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(54) Title: METHODS AND SYSTEMS FOR PROCESSING MICROFEATURE WORKPIECES WITH FLOW AGITATORS AND/OR MULTIPLE ELECTRODES

(57) Abstract: Tools having mounting modules with registration systems are disclosed. The mounting includes positioning elements for precisely locating a reactor and a workpiece transport that moves workpieces to and for the reactor. The relative positions between positioning elements of the reactor are fixed so that the workpiece transport does not need to be recalibrated when the reactor is removed and replaced with another reactor. The reactor includes an agitator for agitating processing fluid at a process surface of the workpiece. The agitator, the reactor, and electrodes within the reactor are configured to reduce the likelihood for electrical shadowing created by the agitator at the surface of the workpiece, and to account for three-dimensional effects on the electrical field as the agitator and/or the workpiece reciprocate relative to each other.

METHODS AND SYSTEMS FOR PROCESSING MICROFEATURE WORKPIECES WITH FLOW AGITATORS AND/OR MULTIPLE ELECTRODES

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims priority to pending U.S. Provisional Application No. 60/484,603, filed July 1, 2003; pending U.S. Provisional Application No. 60/484,604, filed July 1, 2003; pending U.S. Provisional Application No. 60/476,786, filed June 6, 2003; pending U.S. Application No. 10/734,098, filed December 11, 2003; and pending U.S. Application No. 10/734,100, filed December 11, 2003, all of which are incorporated herein in their entireties by reference.

TECHNICAL FIELD

The present invention is directed toward methods and systems for processing microfeature workpieces with flow agitators and/or multiple electrodes, including reactors and tools having multiple electrodes and/or enclosed reciprocating agitators.

BACKGROUND

Microdevices are manufactured by depositing and working several layers of materials on a single substrate to produce a large number of individual devices. For example, layers of photoresist, conductive materials, and dielectric materials are deposited, patterned, developed, etched, planarized, and otherwise manipulated to form features in and/or on a substrate. The features are arranged to form integrated circuits, micro-fluidic systems, and other structures.

Wet chemical processes are commonly used to form features on microfeature workpieces. Wet chemical processes are generally performed in wet chemical processing tools that have a plurality of individual processing chambers for cleaning, etching, electrochemically depositing materials, or performing combinations of these processes. Each chamber typically includes a vessel in which wet processing fluids are received, and a workpiece support (e.g., a lift-rotate

unit) that holds the workpiece in the vessel during processing. A robot moves the workpiece into and out of the chambers.

One concern with integrated wet chemical processing tools is that the processing chambers must be maintained and/or repaired periodically. In electrochemical deposition chambers, for example, consumable electrodes degrade over time because the reaction between the electrodes and the electrolytic solution decomposes the electrodes. The shapes of the consumable electrodes accordingly change, causing variations in the electrical field. As a result, consumable electrodes must be replaced periodically to maintain the desired deposition parameters across the workpiece. The electrical contacts that contact the workpiece also may need to be cleaned or replaced periodically. To maintain or repair electrochemical deposition chambers, they are typically removed from the tool and replaced with an extra chamber.

One problem with repairing or maintaining existing wet chemical processing chambers is that the tool must be taken offline for an extended period of time to remove and replace the processing chamber. When the processing chamber is removed from the tool, a pre-maintained processing chamber is mounted in its place. The robot and the lift-rotate unit are then recalibrated to operate with the new processing chamber. Recalibrating the robot and the lift-rotate unit is a time-consuming process that increases the downtime for repairing or maintaining processing chambers. As a result, when only one processing chamber of the tool does not meet specifications, it is often more efficient to continue operating the tool without stopping to repair the one processing chamber until more processing chambers do not meet the performance specifications. The loss of throughput of a single processing chamber, therefore, is not as severe as the loss of throughput caused by taking the tool offline to repair or maintain a single one of the processing chambers.

The practice of operating the tool until at least two processing chambers do not meet specifications severely impacts the throughput of the tool. For example, if the tool is not repaired or maintained until at least two or three processing chambers are out of specification, then the tool operates at only a fraction of its full capacity for a period of time before it is taken offline for maintenance. This increases the operating costs of the tool because the throughput not only suffers while the tool is

offline to replace the wet processing chambers and recalibrate the robot, but the throughput is also reduced while the tool is online because it operates at only a fraction of its full capacity. Moreover, as the feature sizes of the processed workpiece decrease, the electrochemical deposition chambers must consistently meet much higher performance specifications. This causes the processing chambers to fall out of specification sooner, which results in shutting down the tool more frequently. Therefore, the downtime associated with repairing and/or maintaining electrochemical deposition chambers and other types of wet chemical processing chambers is significantly increasing the cost of operating wet chemical processing tools.

The electrochemical deposition chambers housed in the tool may also suffer from several drawbacks. For example, during electrolytic processing in these chambers, a diffusion layer develops at the surface of the workpiece in contact with an electrolytic liquid. The concentration of the material applied to or removed from the workpiece varies over the thickness of the diffusion layer. In many cases, it is desirable to reduce the thickness of the diffusion layer so as to allow an increase in the speed with which material is added to or removed from the workpiece. In other cases, it is desirable to otherwise control the material transfer at the surface of the workpiece, for example, to control the composition of an alloy deposited on the surface, or to more uniformly deposit materials in surface recesses having different aspect ratios.

One approach to reducing the diffusion layer thickness is to increase the flow velocity of the electrolyte at the surface of the workpiece. For example, some vessels include paddles that translate or rotate adjacent to the workpiece to create a high speed, agitated flow at the surface of the workpiece. In one particular arrangement, the workpiece is spaced apart from an anode by a first distance along a first axis (generally normal to the surface of the workpiece) during processing. A paddle having a height of about 25% of the first distance along the first axis oscillates between the workpiece in the anode along a second axis transverse to the first axis. In other arrangements, the paddle rotates relative to the workpiece. In still further arrangements, fluid jets are directed at the workpiece to agitate the flow at the workpiece surface.

The foregoing arrangements suffer from several drawbacks. For example, it is often difficult even with one or more paddles or fluid jets, to achieve the flow velocities necessary to significantly reduce the diffusion layer thickness at the surface of the workpiece. Furthermore, when a paddle is used to agitate the flow adjacent to the microfeature workpiece, it can create "shadows" in the electrical field within the electrolyte, causing undesirable nonuniformities in the deposition or removal of material from the microfeature workpiece. Still further, a potential drawback associated with rotating paddles is that they may be unable to accurately control radial variations in the material application/removal process, because the speed of the paddle relative to the workpiece varies as a function of the radius and has a singularity at the center of the workpiece.

The reactors in which such paddles are positioned may also suffer from several drawbacks. For example, the electrode in the reactor may not apply or remove material from the workpiece in a spatially uniform manner, causing some areas of the workpiece to gain or lose material at a greater rate than others. Existing devices are also not configured to transfer material to and/or from different types of workpieces without requiring lengthy, unproductive time intervals between processing periods, during which the devices must be reconfigured (for example, by moving the electrode and/or a shield to adjust the electric field within the electrolyte). Another drawback is that the paddles can disturb the uniformity of the electric field created by the electrode, which further affects the uniformity with which material is applied to or removed from the workpiece. Still another drawback with the foregoing arrangements is that the vessel may also include a magnet positioned proximate to the workpiece to control the magnetic orientation of material applied to the workpiece. When the electrode is removed from the vessel for servicing or replacement, it has been difficult to do so without interfering with and/or damaging the magnet.

SUMMARY

The present invention is a tool that includes a processing chamber having an agitator, a workpiece transport for moving workpieces to and from the processing chamber, and a registration system for locating the processing chamber and the

transport relative to each other. The tool includes a mounting module having positioning elements and attachment elements for engaging the chamber and the transport. The positioning elements maintain their relative positions so that the transport does not need to be recalibrated when the processing chamber is removed and replaced with another processing chamber.

In a particularly useful embodiment of the tool, the mounting module includes a deck that has a rigid outer member, a rigid interior member, and bracing between the outer member and the interior member. The processing chamber is then attached to the deck. The module further includes a platform that has positioning elements for locating the transport.

In further useful embodiments, the agitator in the processing chamber is positioned within an agitator chamber, with tight clearances around the agitator to increase the fluid agitation, and therefore enhance mass transfer effects at the surface of the workpiece. The agitator can include multiple agitator elements and can reciprocate through a stroke that changes position over time to reduce the likelihood for electrically shadowing the workpiece. Multiple electrodes (e.g., including a thieving electrode) provide spatial and temporal control over the current density at the surface of the workpiece. An electric field control element can be positioned between electrodes of the chamber and the process location to circumferentially vary the electric current density in the processing fluid at different parts of the process location, thereby counteracting potential three-dimensional effects created by the paddles as they reciprocate relative to the workpiece. A magnet can be positioned proximate to a location at which the workpiece is processed (e.g., to control the application of magnetically directional materials) but not adjacent the path along which an electrode is moved when it is installed or removed.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic top plan view of a wet chemical processing tool in accordance with an embodiment of the invention.

Figure 2A is an isometric view illustrating a portion of a wet chemical processing tool in accordance with an embodiment of the invention.

Figure 2B is a top plan view of a wet chemical processing tool arranged in accordance with an embodiment of the invention.

Figure 3 is an isometric view of a mounting module for use in a wet chemical processing tool in accordance with an embodiment of the invention.

Figure 4 is cross-sectional view along line 4-4 of Figure 3 of a mounting module for use in a wet chemical processing tool in accordance with an embodiment to the invention.

Figure 5 is a cross-sectional view showing a portion of a deck of a mounting module in greater detail.

Figure 6A is a partially schematic, isometric illustration of a processing station having features configured in accordance with an embodiment of the invention.

Figure 6B is a top isometric view of the processing station shown in Figure 6A.

Figures 6C and 6D are schematic illustrations of a reactor having agitators and electrodes configured in accordance with embodiments of the invention.

Figure 6E is a partially schematic, isometric illustration of an actuated agitator configured in accordance with an embodiment of the invention.

Figure 7 is a partially cutaway, isometric illustration of a reactor having electrodes and a magnet positioned relative to an agitator chamber in accordance with another embodiment of the invention.

Figure 8 is a partially schematic, cross-sectional view of the reactor shown in Figure 7.

Figure 9 is a schematic illustration of an electric field control element configured to circumferentially vary the effect of an electrode in accordance with an embodiment of the invention.

Figure 10 is a partially schematic illustration of another embodiment of an electric field control element.

Figure 11 is a partially schematic, isometric illustration of an electric field control element that also functions as a gasket in accordance with an embodiment of the invention.

Figures 12A-12G illustrate agitators having shapes and configurations in accordance with further embodiments of the invention.

Figure 13 is an isometric illustration of an agitator having a grid configuration.

Figure 14 schematically illustrates flow into and out of an agitator chamber in accordance with an embodiment of the invention.

Figure 15 is a partially schematic illustration of a reactor having an agitator chamber in accordance with another embodiment of the invention.

Figures 16A-16B illustrate a bottom plan view and a cross-sectional view, respectively, of a portion of an agitator chamber having agitator elements of different sizes in accordance with yet another embodiment of the invention.

Figure 17 is a cross-sectional view of a plurality of agitators that reciprocate within an envelope in accordance with another embodiment of the invention.

Figure 18 is a partially schematic, isometric illustration of an agitator element having a height that changes over its length.

Figures 19A-19F schematically illustrate a pattern for shifting the reciprocation stroke of agitator elements in accordance with an embodiment of the invention.

DETAILED DESCRIPTION

As used herein, the terms "microfeature workpiece" or "workpiece" refer to substrates on and/or in which microelectronic devices are integrally formed. Typical microdevices include microelectronic circuits or components, thin-film recording heads, data storage elements, microfluidic devices, and other products. Micromachines or micromechanical devices are included within this definition because they are manufactured using much of the same technology that is used in the fabrication of integrated circuits. The substrates can be semiconductive pieces (e.g., doped silicon wafers or gallium arsenide wafers), nonconductive pieces (e.g., various ceramic substrates), or conductive pieces. In some cases, the workpieces are generally round and in other cases, the workpieces have other shapes, including rectilinear shapes.

Several embodiments of integrated tools for wet chemical processing of microfeature workpieces are described in the context of depositing metals or electrophoretic resist in or on structures of a workpiece. The integrated tools in accordance with the invention, however, can also be used in etching, rinsing or

other types of wet chemical processes in the fabrication of microfeatures in and/or on semiconductor substrates or other types of workpieces. Several examples of tools and chambers in accordance with the invention are set forth in Figures 1-19F and the following text to provide a thorough understanding of particular embodiments of the invention. The description is divided into the following sections: (A) Embodiments of Integrated Tools With Mounting Modules; (B) Embodiments of Dimensionally Stable Mounting Modules; (C) Embodiments of Reactors Having Multiple Electrodes and Enclosed Agitators; (D) Embodiments of Reactors Having Electric Field Control Elements to Circumferentially Vary an Electric Field; (E) Embodiments of Agitators for Agitator Chambers; and (F) Embodiments of Reactors Having Agitators and Reciprocation Schedules to Reduce Electric Field Shielding. A person skilled in the art will understand, however, that the invention may have additional embodiments, and that the invention may be practiced without several of the details of the embodiments shown in Figures 1-19F.

A. <u>Embodiments of Integrated Tools With Mounting Modules</u>

Figure 1 schematically illustrates an integrated tool 100 that can perform one or more wet chemical processes. The tool 100 includes a housing or cabinet 102 that encloses a deck 164, a plurality of wet chemical processing stations 101, and a workpiece transport or transport system 105. Each processing station 101 includes a vessel, chamber, or reactor 110 and a workpiece support (for example, a lift-rotate unit) 113 for transferring microfeature workpieces W into and out of the reactor 110. The stations 101 can include rinse/dry chambers, cleaning capsules, etching capsules, electrochemical deposition chambers, or other types of wet chemical processing vessels. The transport system 105 includes a linear track 104 and a robot 103 that moves along the track 104 to transport individual workpieces W within the tool 100. The integrated tool 100 further includes a workpiece load/unload unit 108 having a plurality of containers 107 for holding the workpieces W. In operation, the robot 103 transports workpieces W to/from the containers 107 and the processing stations 101 according to a predetermined workflow schedule within the tool 100.

Figure 2A is an isometric view showing a portion of an integrated tool 100 in accordance with an embodiment of the invention. The integrated tool 100 includes

a frame 162, a dimensionally stable mounting module 160 mounted to the frame 162, a plurality of wet chemical processing chambers 110, and a plurality of workpiece supports 113. The mounting module 160 carries the processing chambers 110 and the workpiece supports 113, as well as the transport system 105.

The frame 162 has a plurality of posts 163 and cross-bars 161 that are welded together in a manner known in the art. A plurality of outer panels and doors (not shown in Figure 2A) are generally attached to the frame 162 to form an enclosed cabinet 102 (Figure 1). The mounting module 160 is at least partially housed within the frame 162. In one embodiment, the mounting module 160 is carried by the cross-bars 161 of the frame 162, but the mounting module 160 can alternatively stand directly on the floor of the facility or other structures.

The mounting module 160 is a rigid, stable structure that maintains the relative positions between the wet chemical processing chambers 110, the workpiece supports 113, and the transport system 105. One aspect of the mounting module 160 is that it is much more rigid and has a significantly greater structural integrity than the frame 162 so that the relative positions between the wet chemical processing chambers 110, the workpiece supports 113, and the transport system 105 do not change over time. Another aspect of the mounting module 160 is that it includes a dimensionally stable deck 164 with positioning elements at precise locations for positioning the processing chambers 110 and the workpiece supports 113 at known locations on the deck 164. In one embodiment (not shown), the transport system 105 is mounted directly to the deck 164. In an arrangement shown in Figure 2A, the mounting module 160 also has a dimensionally stable platform 165 and the transport system 105 is mounted to the platform 165. The deck 164 and the platform 165 are fixedly positioned relative to each other so that positioning elements on the deck 164 and positioning elements on the platform 165 do not move relative to each other. The mounting module 160 accordingly provides a system in which wet chemical processing chambers 110 and workpiece supports 113 can be removed and replaced with interchangeable components in a manner that accurately positions the replacement components at precise locations on the deck 164.

The tool 100 is particularly suitable for applications that have demanding specifications which require frequent maintenance of the wet chemical processing

chambers 110, the workpiece support 113, or the transport system 105. A wet chemical processing chamber 110 can be repaired or maintained by simply detaching the chamber from the processing deck 164 and replacing the chamber 110 with an interchangeable chamber having mounting hardware configured to interface with the positioning elements on the deck 164. Because the mounting module 160 is dimensionally stable and the mounting hardware of the replacement processing chamber 110 interfaces with the deck 164, the chambers 110 can be interchanged on the deck 164 without having to recalibrate the transport system 105. This is expected to significantly reduce the downtime associated with repairing or maintaining the processing chambers 110 so that the tool 100 can maintain a high throughput in applications that have stringent performance specifications.

Figure 2B is a top plan view of the tool 100 illustrating the transport system 105 and the load/unload unit 108 attached to the mounting module 160. Referring to Figures 2A and 2B together, the track 104 is mounted to the platform 165 and in particular, interfaces with positioning elements on the platform 165 so that it is accurately positioned relative to the chambers 110 and the workpiece supports 113 attached to the deck 164. The robot 103 (which includes end-effectors 106 for grasping the workpiece W) can accordingly move the workpiece W in a fixed, dimensionally stable reference frame established by the mounting module 160. Referring to Figure 2B, the tool 100 can further include a plurality of panels 166 attached to the frame 162 to enclose the mounting module 160, the wet chemical processing chambers 110, the workpiece supports 113, and the transport system 105 in the cabinet 102. Alternatively, the panels 166 on one or both sides of the tool 100 can be removed in the region above the processing deck 164 to provide an open tool.

B. Embodiments of Dimensionally Stable Mounting Modules

Figure 3 is an isometric view of a mounting module 160 configured in accordance with an embodiment of the invention for use in the tool 100 (Figures 1-2B). The deck 164 includes a rigid first panel 166a and a rigid second panel 166b superimposed underneath the first panel 166a. The first panel 166a is an outer member and the second panel 166b is an interior member juxtaposed to the outer member. Alternatively, the first and second panels 166a and 166b can have

different configurations than the one shown in Figure 3. A plurality of chamber receptacles 167 are disposed in the first and second panels 166a and 166b to receive the wet chemical processing chambers 110 (Figure 2A).

The deck 164 further includes a plurality of positioning elements 168 and attachment elements 169 arranged in a precise pattern across the first panel 166a. The positioning elements 168 include holes machined in the first panel 166a at precise locations, and/or dowels or pins received in the holes. The dowels are also configured to interface with the wet chemical processing chambers 110 (Figure 2A). For example, the dowels can be received in corresponding holes or other interface members of the processing chambers 110. In other embodiments, the positioning elements 168 include pins, such as cylindrical pins or conical pins, that project upwardly from the first panel 166a without being positioned in holes in the first panel 166a. The deck 164 has a set of first chamber positioning elements 168a located at each chamber receptacle 167 to accurately position the individual wet chemical processing chambers at precise locations on the mounting module 160. The deck 164 can also include a set of first support positioning elements 168b near each receptacle 167 to accurately position individual workpiece supports 113 (Figure 2A) at precise locations on the mounting module 160. The first support positioning elements 168b are positioned and configured to mate with corresponding positioning elements of the workpiece supports 113. The attachment elements 169 can be threaded holes in the first panel 166a that receive bolts to secure the chambers 110 and the workpiece supports 113 to the deck 164.

The mounting module 160 also includes exterior side plates 170a along longitudinal outer edges of the deck 164, interior side plates 170b along longitudinal inner edges of the deck 164, and endplates 170c attached to the ends of the deck 164. The transport platform 165 is attached to the interior side plates 170b and the end plates 170c. The transport platform 165 includes track positioning elements 168c for accurately positioning the track 104 (Figures 2A and 2B) of the transport system 105 (Figures 2A and 2B) on the mounting module 160. For example, the track positioning elements 168c can include pins or holes that mate with corresponding holes, pins or other interface members of the track 104. The transport platform 165 can further include attachment elements 169, such as tapped holes. that receive bolts to secure the track 104 to the platform 165.

Figure 4 is a cross-sectional view illustrating one suitable embodiment of the internal structure of the deck 164, and Figure 5 is a detailed view of a portion of the deck 164 shown in Figure 4. The deck 164 includes bracing 171, such as joists, extending laterally between the exterior side plates 170a and the interior side plates 170b. The first panel 166a is attached to the upper side of the bracing 171, and the second panel 166b is attached to the lower side of the bracing 171. The deck 164 can further include a plurality of throughbolts 172 and nuts 173 that secure the first and second panels 166a and 166b to the bracing 171. As best shown in Figure 5, the bracing 171 has a plurality of holes 174 through which the throughbolts 172 extend. The nuts 173 can be welded to the bolts 172 to enhance the connection between these components.

The panels and bracing of the deck 164 can be made from stainless steel, other metal alloys, solid cast materials, or fiber-reinforced composites. For example, the panels and plates can be made from Nitronic 50 stainless steel, Hastelloy 625 steel alloys, or a solid cast epoxy filled with mica. The fiber-reinforced composites can include a carbon-fiber or Kevlar® mesh in a hardened resin. The material for the panels 166a and 166b should be highly rigid and compatible with the chemicals used in the wet chemical processes. Stainless steel is well-suited for many applications because it is strong but not affected by many of the electrolytic solutions or cleaning solutions used in wet chemical processes. In one embodiment, the panels and plates 166a-b and 170a-c are 0.125 to 0.375 inch thick stainless steel, and more specifically they can be 0.250 inch thick stainless steel. The panels and plates, however, can have different thicknesses in other embodiments.

The bracing 171 can also be stainless steel, fiber-reinforced composite materials, other metal alloys, and/or solid cast materials. In one embodiment, the bracing can be 0.5 to 2.0 inch wide stainless steel joists, and more specifically 1.0 inch wide by 2.0 inches tall stainless steel joists. In other embodiments the bracing 171 can be a honey-comb core or other structures made from metal (e.g., stainless steel, aluminum, titanium, etc.), polymers, fiber glass or other materials.

The mounting module 160 is constructed by assembling the sections of the deck 164, and then welding or otherwise adhering the end plates 170c to the sections of the deck 164. The components of the deck 164 are generally secured

together by the throughbolts 172 without welds. The outer side plates 170a and the interior side plates 170b are attached to the deck 164 and the end plates 170c using welds and/or fasteners. The platform 165 is then securely attached to the end plates 170c, and the interior side plates 170b. The order in which the mounting module 160 is assembled can be varied and is not limited to the procedure explained above.

Returning to Figure 3, the mounting module 160 provides a heavy-duty, dimensionally stable structure that maintains the relative positions between the positioning elements 168a-b on the deck 164 and the positioning elements 168c on the platform 165 within a range that does not require the transport system 105 to be recalibrated each time a replacement processing chamber 110 or workpiece support 113 is mounted to the deck 164. The mounting module 160 is generally a rigid structure that is sufficiently strong to maintain the relative positions between the positioning elements 168a-b and 168c when the wet chemical processing chambers 110, the workpiece supports 113, and the transport system 105 are mounted to the mounting module 160. In several embodiments, the mounting module 160 is configured to maintain the relative positions between the positioning elements 168a-b and 168c to within 0.025 inch. In other embodiments, the mounting module is configured to maintain the relative positions between the positioning elements 168a-b and 168c to within approximately 0.005 to 0.015 inch. As such, the deck 164 often maintains a uniformly flat surface to within approximately 0.025 inch, and in more specific embodiments to approximately 0.005-0.015 inch.

C. Embodiments of Reactors Having Multiple Electrodes and Enclosed Agitators

Figure 6A is an isometric illustration of a processing station 101 having features in accordance with an embodiment of the invention. The station 101 includes a vessel 112 configured to carry an electrochemical processing fluid, a workpiece support 113 positioned to releasably carry a microfeature workpiece W in contact with the processing fluid, and an agitator 140 or other flow control device positioned to agitate the processing fluid proximate to a surface of the microfeature workpiece W. The agitator 140 can include one or more agitator elements 141 (e.g., paddles or paddle elements). In a particular aspect of this embodiment, the workpiece support 113 includes a head 185 carried by a head support 186 which

moves upwardly and downwardly relative to the vessel 112 along a track 187. Conduits 188 provide for fluid and electrical communication between the workpiece support 113 and the rest of the tool 100 (Figure 1) via a first connector 189a (attached to the workpiece support 113) and a second connector 189b (attached to the tool 100).

The head 185 rotates between a face up position (to load and unload the microfeature workpiece W) and a face down position (for processing). When the workpiece W is in the face down position, the head 185 descends to bring the workpiece W into contact with the processing fluid in the vessel 112. The head 185 can also spin the workpiece W about an axis generally normal to the downwardly facing surface of the workpiece W. In one aspect of this embodiment, the head 185 spins the workpiece W to a selected orientation prior to processing (e.g., when the process is sensitive to the orientation of the workpiece W, including during deposition of magnetically responsive materials). In other embodiments, the head 185 spins the workpiece W during processing (e.g., during material application, removal and/or rinsing). In still further embodiments, the head 185 does not spin, e.g., when spinning before, during or after processing is not beneficial to the performed process. In any of these embodiments, the head 185 ascends after processing and then inverts to unload the workpiece W from the processing station 101.

In a particular aspect of an embodiment shown in Figure 6A, the processing station 101 includes a generally horseshoe-shaped magnet 195 disposed around the vessel 112. The magnet 195 includes a permanent magnet and/or an electromagnet positioned to orient molecules of material applied to the workpiece W in a particular direction. For example, such an arrangement is used to apply permalloy and/or other magnetically directional materials to the workpiece W. In other embodiments, the magnet 195 is eliminated.

Figure 6B is a top isometric view of an embodiment of the processing station 101 described above with reference to Figure 6A, with the workpiece support 113 removed for purposes of illustration. As shown in Figure 6B, the agitator elements 141 are positioned in a chamber 130 (e.g., an agitator chamber or flow control chamber) just beneath the microfeature workpiece W (which is shown in phantom lines in Figure 6B). Accordingly, the microfeature workpiece W forms a portion of a

top surface for the agitator chamber 130. In a particular aspect of this embodiment, processing fluid is introduced into the agitator chamber 130 laterally (as represented by arrow A) so as to traverse the agitator chamber 130 and emerge from beneath the workpiece W through collection ports 139a (as indicated by arrows B). The processing fluid then travels around the agitator chamber 130 as indicated by arrows C and is collected in a series of drain ports 139b for removal or recirculation (as indicated by arrow D). Accordingly, in one embodiment, the drain ports 139b define a fluid plane at the maximum height of the processing fluid in the vessel. At least a portion of the agitator chamber 130 (and, as shown in Figure 6B, the entirety of the agitator chamber 130) is immersed in processing fluid beneath the fluid plane. While the processing fluid moves through the agitator chamber 130, the agitator elements 141, positioned just beneath the workpiece W, reciprocate back and forth along a generally linear motion path (as indicated by arrow E) to enhance the mass transfer process at the surface of the workpiece W.

Figure 6C is a schematic illustration of a reactor 110 configured to process microfeature workpieces in accordance with an embodiment of the invention. The reactor 110 includes an inner vessel 112 disposed within an outer vessel 111. Processing fluid (e.g., an electrolyte) is supplied to the inner vessel 112 at an inlet 116 and flows upwardly over a weir 118 to the outer vessel 111. The processing fluid exits the reactor 110 at a drain 117. An electrode 121 is positioned in the inner vessel 112 and an agitator chamber 130 is positioned downstream of the electrode 121. The agitator chamber 130 includes an agitator 140 (e.g., a paddle device) having agitator elements 141 (e.g., paddles) that reciprocate back and forth relative to a central position 180, as indicated by arrow R. The chamber 130 also has an aperture 131 defining a process location P. A microfeature workpiece W is supported at the process location P by a workpiece support 113, so that a downwardly facing process surface 109 of the workpiece W is in contact with the processing fluid. The workpiece support 113 can rotate or not rotate, depending on the nature of the process carried out on the workpiece W. The workpiece support 113 also includes a workpiece contact 115 (e.g., a ring contact) that supplies electrical current to the front surface or back surface of the workpiece W. A seal 114 extends around the workpiece contact 115 to protect it from exposure to the processing fluid. In another arrangement, the seal 114 can be eliminated.

During electrolytic deposition, the workpiece contact 115 and the workpiece W function as a cathode, and the electrode 121 functions as an anode. The processing fluid flows past the electrode 121 and through the paddle chamber 130 to supply ions to the process surface 109 of the workpiece W. During electroetching, the workpiece W functions as an anode and the electrode 121 functions as a cathode to remove material from the process surface 109. In other embodiments, the mass transfer process includes other deposition processes (e.g., electroless deposition) or other material removal processes. In any of these arrangements, the processing fluid flows through the agitator chamber 130 while the agitator elements 141 reciprocate adjacent to the workpiece W to enhance the mass transfer process taking place at the process surface 109. The shapes, sizes and configurations of the agitator elements 141, the manner in which they reciprocate, and the confined volume of the agitator chamber 130 further enhance the mass transfer process and reduce the impact of the agitator elements 141 on the electric field in the reactor 110. Further aspects of these features are described later with reference to Figures 7-19F.

Figure 6D is a schematic illustration of the reactor 110 having an electrode support 120 configured in accordance with another embodiment of the invention. The electrode support 120 includes a plurality of generally annular electrode compartments 122, separated by compartment walls 123. A corresponding plurality of annular electrodes 121 are positioned in the electrode compartments 122. The compartment walls 123 are formed from a dielectric material, and the gaps between the top edges of the compartment walls 123 define a composite virtual anode location V just beneath the agitator chamber 130. As used herein, the terms "virtual anode location" and "virtual electrode location" refer to a plane spaced apart from the physical anodes or electrodes through which all the current flux for one or more of the electrodes or anodes passes. The polarity of the electrical potential applied to each of the electrodes 121, and/or the current flowing through each of the electrodes 121, may be selected to control a manner in which material is added to or removed from the workpiece W at the process location P. Alternatively, the electrodes 121 may be eliminated when the reactor 110 is used to perform processes (such as electroless deposition processes) that still benefit from

enhanced mass transfer effects at the process surface 109, provided by the agitator 140.

Figure 6E is a partially schematic, isometric illustration of an agitator system 142 having an agitator 140 configured in accordance with an embodiment of the invention. The agitator 140 includes a plurality of agitator elements 141 (six are shown in Figure 3), each having outwardly facing agitator surfaces 147. Accordingly, the agitator surfaces 147 of neighboring agitator elements 141 are spaced apart from each other. The agitator 140 further includes a support 144 that is driven by a motor 143 to move the agitator 140 in a linear, reciprocal manner, as indicated by arrow R. The motor 143 is coupled to the support 144 with a coupler 145 (e.g., a lead screw). A bellows 146 is positioned around the coupler 145 and protects the coupler 145 from exposure to the processing fluid described above. A controller 152 directs the motion of the agitator 140. Elongated flow restrictors extend transverse to the agitator elements 141 to restrict and/or prevent fluid from escaping directly out of the agitator chamber 130 (Figure 2). As discussed later (e.g., with reference to Figures 12A-13), the agitator elements 141 are shaped to agitate the processing fluid in which they reciprocate, without creating a significant impact on the local electric field.

Figure 7 is a partially schematic, cutaway illustration of a reactor 710 configured in accordance with another embodiment of the invention. The reactor 710 includes a lower portion 719a, an upper portion 719b above the lower portion 719a, and an agitator chamber 730 above the upper portion 719b. The lower portion 719a houses an electrode support or pack 720 which in turn houses a plurality of annular electrodes 721 (shown in Figure 7 as electrodes 721a-721d). The lower portion 719a is coupled to the upper portion 719b with a clamp 726. A perforated gasket 727 positioned between the lower portion 719a and the upper portion 719b allows fluid and electrical communication between these two portions.

The agitator chamber 730 can include a base 733, and a top 734 having an aperture 731 at the process location P. The agitator chamber 730 houses an agitator 740 having multiple agitator elements 741 that reciprocate back and forth beneath the workpiece W (shown in phantom lines in Figure 7) at the process location P. A magnet 795 is positioned adjacent to the process location P to control the orientation of magnetically directional materials deposited on the workpiece W

by the processing fluid. An upper ring portion 796 positioned above the process location P collects exhaust gases during electrochemical processing, and collects rinse fluid during rinsing. The rinse fluid is provided by one or more nozzles 798. In one embodiment, the nozzle 798 projects from the wall of the upper ring portion 796. In other embodiments, the nozzle or nozzles 798 are flush with or recessed from the wall. In any of these arrangements, the nozzle or nozzles 798 are positioned to direct a stream of fluid (e.g., a rinse fluid) toward the workpiece W when the workpiece W is raised above the process location P and, optionally, while the workpiece W spins. Accordingly, the nozzle(s) 798 provide an in-situ rinse capability, to quickly rinse processing fluid from the workpiece W after a selected processing time has elapsed. This reduces inadvertent processing after the elapsed time, which might occur if chemically active fluids remain in contact with the workpiece W for even a relatively short post-processing time prior to rinsing.

Processing fluid enters the reactor 710 through an inlet 716. Fluid proceeding through the inlet 716 fills the lower portion 719a and the upper portion 719b, and can enter the agitator chamber 730 through a permeable portion 733a of the base 733, and through gaps in the base 733. Some of the processing fluid exits the reactor 710 through first and second flow collectors, 717a, 717b. Additional processing fluid enters the agitator chamber 730 directly from an entrance port 716a and proceeds through a gap in a first wall 732a, laterally across the agitator chamber 730 to a gap in a second wall 732b. At least some of the processing fluid within the agitator chamber 730 rises above the process location P and exits through drain ports 797..

The reactor 710 is mounted to a rigid deck 764 in a manner generally similar to that described above with reference to Figures 2A-5. Accordingly, the deck 764 includes a first panel 766a supported relative to a second panel 766b by fasteners and bracing (not shown in Figure 7). Chamber positioning elements 768a (e.g., dowel pins) project upwardly from the first panel 766a and are received in precisely positioned holes in a base plate 777 of the reactor 710. The base plate 777 is attached to the deck 764 with fasteners (not shown in Figure 7), e.g., nuts and bolts. The base plate 777 is also aligned and fastened to the rest of the reactor 710 with additional dowels and fasteners. Accordingly, the reactor 710 (and any replacement reactor 710) is precisely located relative to the deck 764, the corresponding

workpiece support 113 (Figure 1) and the corresponding transport system 105 (Figure 1).

One feature of the arrangement shown in Figure 7 is that the lower portion 719a (which houses the electrode support 720) is coupled to and decoupled from the upper portion 719b by moving the electrode support 720 along an installation/removal axis A, as indicated by arrow F. Accordingly, the electrode support 720 need not pass through the open center of the magnet 795 during installation and removal. An advantage of this feature is that the electrode support 720 and/or the electrodes 721 (which may include a magnetically responsive material, such as a ferromagnetic material) will be less likely to be drawn toward the magnet 795 during installation and/or removal. This feature can make installation of the electrode support 720 substantially simpler. For example, this feature can eliminate the need for specialized hoist equipment to handle installation and/or removal of the magnet 745. This feature can also reduce the likelihood for damage to either the electrode support 720 or other portions of the reactor 710 (including the magnet 795). Such damage can result from collisions caused by the attractive forces between the magnet 795 and the electrode support 720 or electrodes 721.

Figure 8 is a cross-sectional side elevation view of an embodiment of the reactor 710 taken substantially along line 8-8 of Figure 7. The lower and upper portions 719a, 719b include multiple compartment walls 823 (four are shown in Figure 8 as compartment walls 823a-823d) that divide the volume within these portions into a corresponding plurality of annular compartments 822 (four are shown in Figure 8 as compartments 822a-822d), each of which houses one of the electrodes 721. The gaps between adjacent compartment walls 823 (e.g., at the tops of the compartment walls 823) provide for "virtual electrodes" at these locations. The permeable base portion 733a can also provide a virtual electrode location.

The electrodes 721a-721d are coupled to a power supply 828 and a controller 829. The power supply 828 and the controller 829 together control the electrical potential and current applied to each of the electrodes 721a-721d, and the workpiece W. Accordingly, an operator can control the rate at which material is applied to and/or removed from the workpiece W in a spatially and/or temporally varying manner. In particular, the operator can select the outermost electrode 721d

to operate as a current thief. Accordingly, during a deposition process, the outermost electrode 721d attracts ions that would otherwise be attracted to the workpiece W. This can counteract the terminal effect, e.g., the tendency for the workpiece W to plate more rapidly at its periphery than at its center when the workpiece contact 115 (Figure 6) contacts the periphery of the workpiece W. Alternatively, the operator can temporally and/or spatially control the current distribution across the workpiece W to produce a desired thickness distribution of applied material (e.g., flat, edge thick, or edge thin).

One advantage of the foregoing arrangement is that the multiple electrodes provide the operator with increased control over the rate and manner with which material is applied to or removed from the workpiece W. Another advantage is that the operator can account for differences between consecutively processed workpieces or workpiece batches by adjusting the current and/or electric potential applied to each electrode, rather than physically adjusting parameters of the reactor 710..

When the outermost electrode 721d operates as a current thief, it is desirable to maintain electrical isolation between the outermost electrode 721d on the one hand and the innermost electrodes 721a-721c on the other. Accordingly, the reactor 710 includes a first return flow collector 717a and a second return flow collector 717b. The first return flow collector 717a collects flow from the innermost three electrode compartments 822a-822c, and the second return flow collector 717b collects processing fluid from the outermost electrode compartment 822d to maintain electrical isolation for the outermost electrode 721d. By draining the processing fluid downwardly toward the electrodes 721, this arrangement can also reduce the likelihood for particulates (e.g., flakes from consumable electrodes) to enter the agitator chamber 730. By positioning the outermost electrode 721d remotely from the process location P, it can be easily removed and installed without disturbing structures adjacent to the process location P. This is unlike some existing arrangements having current thieves positioned directly adjacent to the process location.

One feature of an embodiment of the reactor 710 described above with reference to Figures 7 and 8 is that the electrodes 721 are positioned remotely from the process location P. An advantage of this feature is that the desired distribution

of current density at the process surface 109 of the workpiece W can be maintained even when the electrodes 721 change shape. For example, when the electrodes 721 include consumable electrodes and change shape during plating processes, the increased distance between the electrodes 721 and the process location P reduces the effect of the shape change on the current density at the process surface 109, when compared with the effect of electrodes positioned close to the process location P. This advantage applies as well to electrodes that operate as current thieves and change shape by gaining rather than losing conductive material. Accordingly, such electrodes need not be cleaned as often as electrodes positioned close to the process location P. Another advantage is that shadowing effects introduced by features in the flow path between the electrodes 721 and the workpiece W (for example, the gasket 727) can be reduced due to the increased spacing between the electrodes 721 and the process location P.

In other arrangements, the electrodes 721 have other locations and/or configurations. For example, in one arrangement, the chamber base 733 houses one or more of the electrodes 721. Accordingly, the chamber base 733 may include a plurality of concentric, annular, porous electrodes (formed, for example, from sintered metal) to provide for (a) spatially and/or temporally controllable electrical fields at the process location P, and (b) a flow path into the agitator chamber 730. Alternatively, the agitator elements 741 themselves may be coupled to an electrical potential to function as electrodes, in particular, when formed from a non-consumable material. In still other arrangements, the reactor 710 may include more or fewer than four electrodes, and/or the electrodes may be positioned more remotely from the process location P, and may maintain fluid and electrical communication with the process location P via conduits.

D. Embodiments of Reactors Having Electric Field Control Elements to Circumferentially Vary an Electric Field

Figure 9 is a partially schematic illustration looking downwardly on a reactor 910 having an agitator 940 positioned in an agitator chamber 930 in accordance with an embodiment of the invention. The agitator chamber 930 and the agitator 940 are arranged generally similarly to the agitator chambers and the agitators described above with reference to Figures 6-8. Accordingly, the agitator 940

includes a plurality of agitator elements 941 elongated parallel to an agitator axis 990 and movable relative to a workpiece W (shown in phantom lines in Figure 9) along an agitator motion axis 991.

The elongated agitator elements 941 can potentially affect the uniformity of the electric field proximate to the circular workpiece W in a circumferentially varying manner. Accordingly, the reactor 910 includes features for circumferentially varying the effect of the thieving electrode (not visible in Figure 9) to account for this potential circumferential variation in current distribution.

The agitator chamber 930 shown in Figure 9 includes a base 933 formed by a permeable base portion 933a and by the upper edges of walls 923 that separate the electrode chambers below (a third wall 923c and a fourth or outer wall 923d are visible in Figure 9). The third wall 923c is spaced apart from the permeable base portion 933a by a third wall gap 925c, and the fourth wall 923d is spaced apart from the third wall 923c by a circumferentially varying fourth wall gap 925d. Both gaps 925c and 925d are shaded for purposes of illustration. The shaded openings also represent the virtual anode locations for the outermost two electrodes, in one aspect of this embodiment.

The fourth wall gap 925d has narrow portions 999a proximate to the 3:00 and 9:00 positions shown in Figure 9, and wide portions 999b proximate to the 12:00 and 6:00 positions shown in Figure 9. For purposes of illustration, the disparities between the narrow portions 999a and the wide portions 999b are exaggerated in Figure 9. In a particular example, the narrow portions 999a have a width of about 0.16 inches, and the wide portions 999b have a width of from about 0.18 inches to about 0.22 inches. The narrow portions 999a and the wide portions 999b create a circumferentially varying distribution of the thief current (provided by a current thief located below the fourth wall gap 925d) that is stronger at the 12:00 and 6:00 positions than at the 3:00 and 9:00 positions. In particular, the thief current can have different values at different circumferential locations that are approximately the same radial distance from the center of the process location P and/or the workpiece W. Alternatively, a circumferentially varying fourth wall gap 925d or a circumferentially varying third wall gap 925c or other gap can be used to deliberately create a three dimensional effect, for example on a workpiece W that has circumferentially varying plating or deplating requirements. One example of such a

workpiece W includes a patterned wafer having an open area (e.g., accessible for plating) that varies in a circumferential manner. In further embodiments, the gap width or other characteristics of the reactor 910 can be tailored to account for the conductivity of the electrolyte in the reactor 910.

Figure 10 illustrates an arrangement in which the region between the third wall 923c and the fourth wall 923d is occupied by a plurality of holes 1025 rather than a gap. The spacing and/or size of the holes 1025 varies in a circumferential manner so that a current thief positioned below the holes 1025 has a stronger effect proximate to the 12:00 and 6:00 positions then proximate to the 3:00 and 9:00 positions.

Figure 11 is a partially cut-away, isometric view of a portion of a reactor 1110 having an electric field control element 1192 that is not part of the agitator chamber. The reactor 1110 includes an upper portion 1119b that replaces the upper portion 719b shown in Figure 7. The electric field control element 1192 is positioned at the lower end of the upper portion 1119b and has openings 1189 arranged to provide a circumferentially varying open area. The openings 1189 are larger at the 12:00 and 6:00 positions than they are at the 3:00 and 9:00 positions. Alternatively, the relative number of openings 1189 (instead of or in addition to the size of openings 1189) may be greater at the 12:00 and 6:00 positions in a manner generally similar to that described above with reference to Figure 10. The upper portion 1119b also includes upwardly extending vanes 1188 that maintain the circumferentially varying electrical characteristics caused by the electric field control element 1192, in a direction extending upwardly to the process location P. The reactor 1110 may include twelve vertically extending vanes 1188, or other numbers of vanes 1188, depending, for example, on the degree to which the open area varies in the circumferential direction.

The electric field control element 1192 also functions as a gasket between the upper portion 1119b and a lower portion 1119a of the reactor 1110, and can replace the gasket 727 described above with reference to Figure 7 to achieve the desired circumferential electric field variation. Alternatively, the electric field control element 1192 may be provided in addition to the gasket 727, for example, at a position below the gasket 727 shown in Figure 7. In either case, an operator can select and install an electric field control element 1192 having open areas

configured for a specific workpiece (or batch of workpieces), without disturbing the upper portion 1119b of the reactor 1110. An advantage of this arrangement is that it reduces the time required by the operator to service the reactor 1110 and/or tailor the electric field characteristics of the reactor 1110 to a particular type of workpiece W.

E. Embodiments of Agitators for Agitator Chambers

Figures 12A-12G illustrate agitator elements 1241a-1241g, respectively, having shapes and other features in accordance with further embodiments of the invention, and being suitable for installation in reactors such as the reactors 110, 710 and 1110 described above. Each of the agitator elements (referred to collectively as agitator elements 1241) has opposing agitator surfaces 1247 (shown as agitator surfaces 1247a-1247g) that are inclined at an acute angle relative to a line extending normal to the process location P. This provides the agitator elements 1241 with a downwardly tapered shape that reduces the likelihood for shadowing or otherwise adversely influencing the electric field created by the electrode or electrodes 121 (Figure 12A) while maintaining the structural integrity of the paddles. The overall maximum width of each agitator element is generally kept as small as possible to further reduce shadowing. For example, the agitator element 1241a (Figure 12A) has a generally diamond-shaped cross-sectional configuration with flat agitator surfaces 1247a. The agitator element 1241b (Figure 12B) has concave agitator surfaces 1247b. The agitator element 1241c (Figure 12C) has convex agitator surfaces 1247c, and the agitator element 1241d (Figure 12D) has flat agitator surfaces 1247d positioned to form a generally triangular shape. In other embodiments, the agitator elements 1241 have other shapes that also agitate the flow at the process location P and reduce or eliminate the extent to which they shadow the electrical field created by the nearby electrode or electrodes 121.

The agitation provided by the agitator elements 1241 may also be supplemented by fluid jets. For example, the agitator element 1241e (Figure 12E) has canted agitator surfaces 1247e that house jet apertures 1248. The jet apertures 1248 can be directed generally normal to the process location P (as shown in Figure 12E); alternatively, the jet apertures 1248 can be directed at other angles relative to the process location P. The processing fluid is provided to the jet apertures 1248

via a manifold 1249 internal to the agitator element 1241e. Jets of processing fluid exiting the jet apertures 1248 increase the agitation at the process location P and enhance the mass transfer process taking place at the process surface 109 of the workpiece W (Figure 6).

Figures 12F and 12G illustrate agitator elements having perforations or other openings that allow the processing fluid to flow through the agitator elements from one side to the other as the agitator elements move relative to the processing fluid. For example, referring first to Figure 12F, the agitator element 1241f has opposing agitator surfaces 1247f, each with pores 1250f. The volume of the agitator element 1241f between the opposing agitator surfaces 1247f is also porous to allow the processing fluid to pass through the agitator element 1241f from one side surface 1247f to the other. The agitator element 1241f may be formed from a porous metal (e.g., titanium) or other materials, such as porous ceramic materials. Figure 12G illustrates an agitator element 1241g having agitator surfaces 1247g with through-holes 1250g arranged in accordance with another embodiment of the invention. Each of the through-holes 1250g extends entirely through the agitator element 1241g along a hole axis 1251, from one agitator surface 1247g to the opposing agitator surface 1247g.

One feature of the agitator elements described above with reference to Figures 12F and 12G is that the holes or pores have the effect of increasing the transparency of the agitator elements to the electric field in the adjacent processing fluid. An advantage of this arrangement is that the pores or holes reduce the extent to which the agitator elements add a three-dimensional component to the electric fields proximate to the workpiece W, and/or the extent to which the agitator elements shadow the adjacent workpiece W. Nonetheless, the agitator elements still enhance the mass transfer characteristics at the surface of the workpiece W by agitating the flow there. For example, the holes or pores in the agitator elements are sized so that the viscous effects of the flow through the agitator elements are strong, and the corresponding restriction by the agitator elements to the flow passing through is relatively high. Accordingly, the porosity of the agitator elements can be selected to provide the desired level of electric field transparency while maintaining the desired level of fluid agitation.

Figure 13 is a partially schematic illustration of an agitator 1340 having a three-dimensional arrangement of agitator elements 1341 (shown in Figure 13 as first agitator elements 1341a and second agitator elements 1341b). The agitator elements 1341a, 1341b are arranged to form a grid, with each of the agitator elements 1341a, 1341b oriented at an acute angle relative to the motion direction R (as opposed to being normal to the motion direction R). Accordingly, the grid arrangement of agitator elements 1341 can increase the agitation created by the agitator 1340 and create a more uniform electric field.

One aspect of the present invention is that, whatever shape and configuration the agitator elements have, they reciprocate within the confines of a close-fitting agitator chamber. The confined volume of the agitator chamber can further enhance the mass transfer effects at the surface of the workpiece W. Further details of the agitator chamber and the manner in which the agitator elements are integrated with the agitator chamber are described below with reference to Figures 14-19F.

F. Embodiments of Reactors Having Agitators and Reciprocation Schedules to Reduce Electric Field Shielding and Improve Mass Transfer Uniformity

Figure 14 is a schematic illustration of the upper portion of a reactor 1410 having an agitator 1440 disposed in a closely confined agitator chamber 1430 in accordance with an embodiment of the invention. The chamber 1430 includes a top 1434 having an aperture 1431 to receive the workpiece W at the process location P. Opposing chamber walls 1432 (shown as a left wall 1432a and a right wall 1432b) extend downwardly away from the top 1434 to a base 1433 that faces toward the process location P.

The agitator 1440 includes a plurality of agitator elements 1441 positioned between the process location P and the chamber base 1433. The agitator 1430 has a height H1 between the process location P and the chamber base 1433, and the agitator elements 1441 have a height H2. The tops of the agitator elements 1441 are spaced apart from the process location P by a gap distance D1, and the bottoms of the agitator elements 1441 are spaced apart from the chamber base 1433 by a gap distance D2. In order to increase the level of agitation in the agitator chamber 1430 and in particular at the process location P, the agitator height H2 is a substantial fraction of the chamber height H1, and the gap distances D1 and D2 are

relatively small. In a particular example, the agitator height H2 is at least 30% of the chamber height H1. In further particular examples, the agitator height H2 is equal to at least 70%, 80%, 90% or more of the chamber height H1. The chamber height H1 can be 30 millimeters or less, e.g., from about 10 millimeters to about 15 millimeters. When the chamber height H1 is about 15 millimeters, the agitator height H2 can be about 10 millimeters, with the gap distances D1 and D2 ranging from about 1 millimeter or less to about 5 millimeters. In yet a further particular example, the chamber height H1 is 15 millimeters, the agitator height H2 is about 11.6 millimeters, D1 is about 2.4 millimeters and D2 is about 1 millimeter. Other arrangements have different values for these dimensions. In any of these arrangements, the amount of flow agitation within the agitator chamber 1430 is generally correlated with the height H2 of the agitator elements 1441 relative to the height H1 of the agitator chamber 1430, with greater relative agitator element height generally causing increased agitation, all other variables being equal.

The plurality of agitator elements 1441 more uniformly and more completely agitates the flow within the agitator chamber 1430 (as compared with a single agitator element 1441) to enhance the mass transfer process at the process surface 109 of the workpiece W. The narrow clearances between the edges of the agitator elements 1441 and (a) the workpiece W above and (b) the chamber base 1433 below, within the confines of the agitator chamber 1430, also increase the level of agitation at the process surface 109. In particular, the movement of the multiple agitator elements 1441 within the small volume of the agitator chamber 1430 forces the processing fluid through the narrow gaps between the agitator elements 1441 and the workpiece W (above) and the chamber base 1433 (below). The confined volume of the agitator chamber 1430 also keeps the agitated flow proximate to the process surface 109.

An advantage of the foregoing arrangement is that the mass transfer process at the process surface 109 of the workpiece W is enhanced. For example, the overall rate at which material is removed from or applied to the workpiece W is increased. In another example, the composition of alloys deposited on the process surface 109 is more accurately controlled and/or maintained at target levels. In yet another example, the foregoing arrangement increases the uniformity with which material is deposited on features having different dimensions (e.g., recesses having

different depths and/or different aspect ratios), and/or similar dimensions. The foregoing results can be attributed to reduced diffusion layer thickness and/or other mass transfer enhancements resulting from the increased agitation of the processing fluid.

The processing fluid enters the agitator chamber 1430 by one or both of two flow paths. Processing fluid following a first path enters the agitator chamber 1430 from below. Accordingly, the processing fluid passes through electrode compartments 1422 of an electrode support 1420 located below the agitator chamber 1430. The processing fluid passes laterally outwardly through gaps between compartment walls 1423 and the chamber base 1433. The chamber base 1433 includes a permeable base portion 1433a through which at least some of the processing fluid passes upwardly into the agitator chamber 1440. The permeable base portion 1433a includes a porous medium, for example, porous aluminum ceramic with 10 micron pore openings and approximately 50% open area. Alternatively, the permeable base portion 1433a may include a series of through-holes or perforations. For example, the permeable base portion 1433a may include a perforated plastic sheet. With any of these arrangements, the processing fluid can pass through the permeable base portion 1433a to supply the agitator chamber 1430 with processing fluid; or (if the permeable base portion 1433a is highly flow restrictive) the processing fluid can simply saturate the permeable base portion 1433a to provide a fluid and electrical communication link between the process location P and annular electrodes 1421 housed in the electrode support 1420, without flowing through the permeable base portion 1433a at a high rate. Alternatively (for example, if the permeable base portion 1433a traps bubbles that interfere with the uniform fluid flow and/or electrical current distribution), the permeable base portion 1433a can be removed, and (a) replaced with a solid base portion, or (b) the volume it would normally occupy can be left open.

Processing fluid following a second flow path enters the agitator chamber 1430 via a flow entrance 1435a. The processing fluid flows laterally through the agitator chamber 1430 and exits at a flow exit 1435b. The relative volumes of processing fluid proceeding along the first and second flow paths can be controlled by design to (a) maintain electrical communication with the electrodes 1421 and (b)

replenish the processing fluid within the agitator chamber 1430 as the workpiece W is processed.

Figure 15 illustrates further details of the reactor 710 described above under Sections C and D. The agitator chamber 730 has a permeable base portion 733a with an upwardly canted conical lower surface 1536. Accordingly, if bubbles are present in the processing fluid beneath the base 733, they will tend to migrate radially outwardly along the lower surface 1536 until they enter the agitator chamber 730 through base gaps 1538 in the base 733. Once the bubbles are within the agitator chamber 730, the agitator elements 741 of the agitator 740 tend to move the bubbles toward an exit gap 1535b where they are removed. As a result, bubbles within the processing fluid will be less likely to interfere with the application or removal process taking place at the process surface 109 of the workpiece W.

The workpiece W (e.g., a round workpiece W having a diameter of 150 millimeters, 300 millimeters or other values) is supported by a workpiece support 1513 having a support seal 1514 that extends around the periphery of the workpiece W. When the workpiece support 1513 lowers the workpiece W to the process location P, the support seal 1514 can seal against a chamber seal 1537 located at the top of the agitator chamber 730. Alternatively, the support seal 1514 can be spaced apart from the chamber seal 1537 to allow fluid and/or gas bubbles to pass out of the agitator chamber 730 and/or to allow the workpiece W to spin or rotate. The processing fluid exiting the agitator chamber 730 through the exit gap 1535b rises above the level of the chamber seal 1537 before exiting the reactor 710. Accordingly, the chamber seal 1537 will tend not to dry out and is therefore less likely to form crystal deposits, which can interfere with its operation. The chamber seal 1537 remains wetted when the workpiece support 1513 is moved upwardly from the process location P (as shown in Figure 15) and, optionally, when the workpiece support 1513 carries the workpiece W at the process location P.

Because the workpiece W is typically not rotated when magnetically directional materials are applied to it (e.g., in conjunction with use of the magnet 795), the linearly reciprocating motion of the plurality of agitator elements 741 is a particularly significant method by which to reduce the diffusion layer thickness by an amount that would otherwise require very high workpiece spin rates to match. For example, a paddle device having six agitator elements 741 moving at .2

meters/second can achieve an iron diffusion layer thickness of less than 18 microns in a permalloy bath. Without the agitator elements, the workpiece W would have to be spun at 500 rpm to achieve such a low diffusion layer thickness, which is not feasible when depositing magnetically responsive materials.

As the linearly elongated agitator elements 741 described above reciprocate transversely beneath a circular workpiece W, they may tend to create three-dimensional effects in the flow field adjacent to the workpiece W. Embodiments of the invention described below with reference to Figures 16A-18 address these effects. For example, Figure 16A is a partially schematic view looking upwardly at a workpiece W positioned just above an agitator 1640 housed in an agitator chamber 1630. Figure 16B is a partially schematic, cross-sectional view of a portion of the workpiece W and the agitator 1640 shown in Figure 16A, positioned above a chamber base 1633 of the agitator 1630 and taken substantially along lines 16B-16B of Figure 16A. As discussed below, the agitator 1640 includes agitator elements having different shapes to account for the foregoing three-dimensional effects.

Referring first to Figure 16A, the agitator 1640 includes a plurality of agitator elements 1641 (shown as four inner agitator elements 1641a positioned between two outer agitator elements 1641b). The agitator elements 1641 are elongated generally parallel to an agitator elongation axis 1690, and reciprocate back and forth along an agitator motion axis 1691, in a manner generally similar to that described above. The workpiece W is carried by a workpiece support 1613 which includes a support seal 1614 extending below and around a periphery of the downwardly facing process surface 109 of the workpiece W to seal an electrical contact assembly 1615.

Because the support seal 1614 projects downwardly away from the process surface 109 of the workpiece W (i.e., outwardly from the plane of Figure 16A), the agitator elements 1641 are spaced more closely to the support seal 1614 than to the process surface 109. When the agitator elements 1641 move back and forth, passing directly beneath the support seal 1614, they can form vortices 1692 and/or high speed jets as flow accelerates through the relatively narrow gap between the agitator elements 1641 and the support seal 1614. For example, the vortices 1692 can form as the agitator elements 1641 pass beneath and beyond the support seal

1614, or the vortices 1692 can form when the agitator elements 1641 become aligned with the support seal 1614 and then pass back over the process surface 109 of the workpiece W. These vortices 1692 may not have a significant impact on the mass transfer at the process surface 109 where the support seal 1614 is generally parallel to the agitator motion axis 1691 (e.g., proximate to the 12:00 and 6:00 positions shown in Figure 16A), but can have more substantial effects where the support seal 1614 is transverse to the agitator motion axis 1691 (e.g., proximate to the 3:00 and 9:00 positions of Figure 16A). As discussed in greater detail below with reference to Figure 16B, the outer agitator elements 1641b (aligned with outer regions of the workpiece W and the process location P) can have a different size than the inner agitator elements 1641a (aligned with the inner regions of the workpiece W and the process location P) to counteract this effect.

Figure 16B illustrates the left outer agitator element 1641b and the left-most inner agitator element 1641a shown in Figure 16A. The inner agitator element 1641a is spaced apart from the workpiece W by a gap distance D1 and from the chamber base 1633 by a gap distance D2. If the inner agitator element 1641a were to reciprocate back and forth beneath the support seal 1614 at the 9:00 position, significant portions of the inner agitator element 1641a would be spaced apart from the support seal 1614 by a gap distance D3, which is significantly smaller than the gap distance D1. As discussed above, this can cause vortices 1692 (Figure 16A) to form, and such vortices can more greatly enhance the mass transfer characteristics at the process surface 109 of the workpiece W at this position than at other positions (e.g., the 12:00 or 6:00 positions). Alternatively, vortices can form across the entire process surface 109, but can be stronger at the 9:00 (and 3:00) positions than at the 12:00 (and 6:00) positions.

To counteract the foregoing effect, the outer agitator element 1641b has a different (e.g., smaller) size than the inner agitator element 1641a so as to be spaced apart from the support seal 1614 by a gap distance D4, which is approximately equal to the gap distance D1 between the inner agitator element 1641a and the workpiece W. Accordingly, the enhanced mass transfer effect at the periphery of the workpiece W (and in particular, at the periphery proximate to the 3:00 and 9:00 positions shown in Figure 16A) can be at least approximately the same as the enhanced mass transfer effects over the rest of the workpiece W.

Figure 17 is a cross-sectional illustration of an agitator 1740 positioned in an agitator chamber 1730 in accordance with another embodiment of the invention. The agitator 1740 includes agitator elements 1741 configured to move within the agitator chamber 1730 in a manner that also reduces disparities between the mass transfer characteristics at the periphery and the interior of the workpiece W. In particular, the agitator elements 1741 move back and forth within an envelope 1781 that does not extend over a support seal 1714 proximate to the 3:00 and 9:00 positions. Accordingly, the agitator elements 1741 are less likely to form vortices (or disparately strong vortices) or other flow field disparities adjacent to the workpiece W proximate to the 3:00 and 6:00 positions.

Figure 18 is an isometric illustration of an agitator element 1841 configured in accordance with another embodiment of the invention. The agitator element 1841 has a height H3 proximate to its ends, and a height H4 greater than H3 at a position between the ends. More generally, the agitator element 1841 can have different cross-sectional shapes and/or sizes at different positions along an elongation axis 1890. In a particular example, the inner agitator elements 1641a described above with reference to Figure 16A may have a shape generally similar to that of the agitator element 1841 shown in Figure 18, for example, to reduce the likelihood for creating disparately enhanced mass transfer effects proximate to the 12:00 and 6:00 positions shown in Figure 16A.

Any of the agitators described above with reference to Figures 6-18 can reciprocate in a changing, repeatable pattern. For example, in one arrangement shown in Figures 19A-19F, the agitator 140 reciprocates one or more times from the central position 180, and then shifts laterally so that the central position 180 for the next reciprocation (or series of reciprocations) is different than for the preceding reciprocation. In a particular embodiment shown in Figures 19A-19F, the central position 180 shifts to five points before returning to its original location. At each point, the agitator 140 reciprocates within an envelope 181 before shifting to the next point. In other particular examples, the central position 181 shifts to from two to twelve or more points. When the central position 181 shifts to twelve points, at each point, the agitator 140 reciprocates within an envelope 181 that extends from about 15-75 millimeters (and still more particularly, about 30 millimeters) beyond the outermost agitator elements 141, and the central position 180 shifts by about 15

millimeters from one point to the next. In other arrangements, the central position 180 shifts to other numbers of points before returning to its original location.

Shifting the point about which the agitator 140 reciprocates reduces the likelihood for forming shadows or other undesirable patterns on the workpiece W. This effect results from at least two factors. First, shifting the central position 180 reduces electric field shadowing created by the physical structure of the agitator elements 141. Second, shifting the central position 180 can shift the pattern of vortices that may shed from each agitator element 141 as it moves. This in turn distributes the vortices (or other flow structures) more uniformly over the process surface 109 of the workpiece W. The agitator element 140 can accelerate and decelerate quickly (for example, at about 8 meters/second^2) to further reduce the likelihood for shadowing. Controlling the speed of the agitator elements 141 will also influence the diffusion layer thickness. For example, increasing the speed of the agitator elements 141 from 0.2 meters/second to 2.0 meters per second is expected to reduce the diffusion layer thickness by a factor of about 3.

The number of agitator elements 141 may be selected to reduce the spacing between adjacent agitator elements 141, and to reduce the minimum stroke length over which each agitator element 141 reciprocates. For example, increasing the number of agitator elements 141 included in the agitator 140 can reduce the spacing between neighboring agitator elements 141 and reduce the minimum stroke length for each agitator element 141. Each agitator element 141 accordingly moves adjacent to only a portion of the workpiece W rather than scanning across the entire diameter of the workpiece W. In a further particular example, the minimum stroke length for each paddle 141 is equal to or greater than the distance between neighboring agitator elements 141. For any of these arrangements, the increased number of agitator elements 141 increases the frequency with which any one portion of the workpiece W has an agitator element 141 pass by it, without requiring the agitator elements 141 to travel at extremely high speeds. Reducing the stroke length of the agitator elements 141 (and therefore, the paddle device 140) also reduces the mechanical complexity of the drive system that moves the agitator elements 141.

From the foregoing, it will be appreciated that specific embodiments of the invention have been described herein for purposes of illustration, but that various

modifications may be made without deviating from the spirit and scope of the invention. For example, features of the agitators and agitator chambers described above in the context of electrolytic processing reactors are also applicable to other reactors, including electroless processing reactors. In another example, the workpiece W reciprocates relative to the agitator. In still a further example, the workpiece W and the agitator need not move relative to each other. In particular, fluid jets issuing from the agitator can provide fluid agitation that enhances the mass transfer process. Nevertheless, at least some aspect of the workpiece W and/or the agitator is activated to provide the fluid agitation and corresponding mass transfer enhancement at the surface of the workpiece W. Accordingly, the invention is not limited except as by the appended claims.

CLAIMS

I/We claim:

1. A tool for wet chemical processing a microfeature workpiece comprising:

a processing support;

a wet chemical processing reactor carried by the processing support, the reactor including a process vessel configured to receive a processing fluid, a workpiece support configured to at least partially immerse a workpiece in a processing fluid at a process location of the vessel, and a processing fluid agitator located within the vessel at least proximate to the process location, the processing fluid agitator having at least one elongated agitator surface with at least one of the agitator and the workpiece support being movable relative to the process location so as to agitate processing fluid at least proximate to the process location, the reactor further including an actuator operatively coupled to at least one of the agitator and the workpiece support; and

a workpiece transport carried by the processing support and being movable relative to the reactor to move a workpiece relative to the reactor.

2. The tool of claim 1 wherein the processing support includes:

a mounting module having a plurality of positioning elements and attachment elements; and

wherein the workpiece support is carried by the mounting module;

wherein the process vessel has a first interface member engaged with one of the positioning elements and a first fastener engaged with one of the attachment elements;

wherein the workpiece transport has a second interface member engaged with one of the positioning elements and a second fastener engaged with one of the attachment elements; and

wherein the mounting module is configured to maintain relative positions between positioning elements such that the workpiece transport does not need to be recalibrated when the process vessel is replaced with another process vessel.

3. The tool of claim 2 wherein the mounting module includes a deck comprising:

a rigid outer member, wherein at least some of the positioning elements and at least some of the attachment elements are on the outer member;

a rigid interior member juxtaposed to the outer member;

bracing between the outer member and the interior member, wherein the outer member, the bracing, and the interior member are fastened together; and

wherein the reactor is attached to the deck.

4. The tool of claim 2 wherein the mounting module includes a deck comprising:

a rigid first panel, wherein at least some of the positioning elements and at least some of the attachment elements are on the first panel;

a rigid second panel juxtaposed to the first panel;

braces between the first and second panels, wherein the first panel, the braces and the second panel are fastened together to be dimensionally stable; and

wherein the reactor is attached to the deck.

5. The tool of claim 2 wherein the mounting module includes a deck comprising:

a plurality of braces;

a rigid first panel attached to one side of the braces and having at least some of (a) the positioning elements and (b) the attachment elements;

a rigid second panel juxtaposed to the first panel and attached to another side of the braces; and

wherein the reactor is attached to first panel of the deck.

6. The tool of claim 2 wherein the mounting module further comprises:

a processing deck comprising an upper panel, a lower panel under the upper panel and braces attached between the upper and lower panels, the upper panel having at least some of (a) the positioning elements and (b) the attachment elements, wherein the first interface member of the reactor is engaged with a corresponding positioning element of the upper panel of the processing deck; and

a platform having at least some of the positioning elements and being fixedly disposed in the tool relative to the processing deck, and wherein the second interface member of the workpiece transport is engaged with a corresponding positioning element of the platform.

7. The tool of claim 2 wherein the mounting module comprises a deck for carrying the reactor, a platform for carrying the workpiece transport, and adjustable footings for adjustably attaching the mounting module to the frame, and wherein:

the deck comprises a plurality of braces, a rigid first panel attached to one side of the braces and having a first set of the positioning elements and a first set of the attachment elements, and a rigid second panel juxtaposed to the first panel and attached to another side of the braces;

the platform comprises a second set of positioning elements and a second set of attachment elements;

the reactor is carried by the deck and includes a plurality of first interface members and a plurality of first fasteners, with the first interface members being engaged with corresponding positioning elements of the first set of positioning elements and the first fasteners being engaged with corresponding attachment elements of the first set of attachment elements; and wherein

the workpiece transport is carried by the platform and includes a plurality of second interface members and a plurality of second fasteners, with the

second interface members being engaged with corresponding positioning elements of the second set of positioning elements and the second fasteners being engaged with corresponding attachments elements of the second set of attachment elements.

8. The tool of claim 2 wherein the mounting module is configured to maintain relative positions between the positioning elements to within 0.025 inch.

9. The tool of claim 2 wherein the mounting module is configured to maintain relative positions between the positioning elements to within approximately 0.005 to 0.015 inch.

10. The tool of claim 1 wherein:

the reactor is a first electrochemical deposition chamber comprising a first vessel, a first workpiece support disposed relative to the first vessel to hold a workpiece in a processing solution, a first cathodic electrode disposed in one of the first vessel and the first workpiece support, and a first anodic electrode disposed in the other of the first vessel and the first workpiece support; and wherein

the tool further comprises a second electrochemical deposition chamber comprising a second vessel, a second workpiece support disposed relative to the second vessel to hold a workpiece in a processing solution, a second cathodic electrode disposed in one of the second vessel or the second workpiece support, and a second anodic electrode disposed in the other of the second vessel or the second workpiece support; further wherein

the workpiece transport is movable to communicate with both the first electrochemical deposition chamber and the second electrical deposition chamber.

11. The tool of claim 1 wherein:

the reactor is a first wet chemical processing chamber comprising a cathodic electrode disposed in one of the vessel and the workpiece support, and an anodic electrode disposed in the other of the vessel and the workpiece support; and wherein

the tool further includes a second wet chemical processing chamber comprising a cleaning chamber having a fluid delivery system that directs a cleaning fluid onto a workpiece; further wherein

the workpiece transport is movable to communicate with both the first and second wet chemical processing chambers.

12. The tool of claim 1 wherein the process location of the vessel is positioned to receive a microfeature workpiece having a maximum width at the process location and wherein the system further comprises a controller operatively coupled to at least one of the agitator and the workpiece support, the controller being configured to move at least one of the agitator and the workpiece support relative to the other along the generally linear path by a distance that is less than the maximum width.

13. The tool of claim 1 wherein the agitator includes a plurality of elongated agitator elements and wherein the system further comprises a controller operatively coupled to the agitator to move each of the agitator elements with a spacing between adjacent agitator elements remaining constant as the agitator moves.

14. The tool of claim 1, further comprising a controller operatively coupled to the at least one of the agitator and the workpiece support, the controller being configured to move the at least one of the agitator and the workpiece support relative to the other in a reciprocal manner along a generally linear axis, with a stroke of the relative motion changing between at least two successive reciprocations.

15. The tool of claim 1 wherein the reactor includes an agitator chamber volume that extends for a first distance generally normal to a plane of the process location, and wherein the agitator is disposed in the agitator chamber volume, and wherein the at least one agitator surfaces extends for a second distance generally normal to the process location, the second distance being at least 30% of the first distance.

16. The tool of claim 15 wherein the agitator chamber includes a plurality of sidewall portions extending downwardly away from the process location, at least one of the sidewall portions including a fluid entrance at least proximate to the process location, at least one of the sidewall portions further including a fluid exit at least proximate to the process location, with the agitator positioned between the fluid entrance and the fluid exit.

17. The tool of claim 15 wherein the second distance is at least 70% of the first distance.

18. The tool of claim 15 wherein the second distance is at least 90% of the first distance.

19. The tool of claim 15 wherein a gap between the process location and an upper extremity of the at least one agitator surface is about five millimeters or less.

20. The tool of claim 15 wherein the chamber volume is bounded by a base portion.

21. The tool of claim 20 wherein the agitator is movable relative to the base portion.

22. The tool of claim 20 wherein the agitator is movable relative to the base portion and wherein a first gap between the process location and an upper

extremity of the at least one agitator surface is about five millimeters or less, and wherein a second gap between the base and a lower extremity of the at least one agitator surface is about five millimeters or less.

23. The tool of claim 20 wherein at least part of the base portion is porous.

24. The tool of claim 20 wherein the chamber volume is bounded by a plurality of sidewall portions extending downwardly away from the process location to the base portion, and wherein the base portion includes a first surface facing toward the process location and a second surface facing opposite from the first surface, and wherein the second surface is inclined to have a higher elevation toward a perimeter of the process location than toward a center of the process location.

25. The tool of claim 1 wherein the agitator includes a plurality of agitator elements having spaced apart surfaces and being reciprocally movable relative to the process location along a generally linear motion axis.

26. The tool of claim 1 wherein the reactor includes a magnet positioned proximate to the process location to orient material deposited on a microfeature workpiece at the process location.

27. The tool of claim 26 wherein the magnet includes a permanent magnet.

28. The tool of claim 1 wherein the reactor includes:

a magnet positioned at least proximate to the process location, the magnet being positioned to impose a magnetic field at the process location to orient material deposited on a microfeature workpiece; and

an electrode support positioned to carry at least one electrode in fluid communication with the process location, the electrode support being movable relative to the vessel between a process position and a

removed position along a motion path that does not pass through the process location.

29. The tool of claim 1 wherein the agitator includes an agitator element having a first surface and a second surface facing opposite from the first surface, the first and second surfaces being canted outwardly and downwardly away from an axis positioned between the surfaces and normal to the process location.

30. The tool of claim 29 wherein the agitator element has a generally diamond shaped cross-section when intersected by a plane generally normal to the process location.

31. The tool of claim 29 wherein the agitator element has a generally triangular cross-sectional shape when intersected by a plane generally normal to the process location.

32. The tool of claim 29 wherein at least one of the first and second surfaces is curved.

33. The tool of claim 1 wherein the agitator is at least partially transmissive to the processing fluid to allow the processing fluid to pass through the agitator.

34. The tool of claim 33 wherein the agitator includes a generally porous material.

35. The tool of claim 33 wherein the agitator includes a plurality of highly flow-restrictive apertures extending from the first surface to the second surface.

36. The tool of claim 1 wherein the agitator includes an electrically conductive material.

37. The tool of claim 1 wherein the agitator includes an electrically insulative material.

38. The tool of claim 1 wherein the agitator includes at least one agitator element elongated along an axis, and wherein the agitator element has different cross-sectional shapes, different cross-sectional sizes, or both different cross-sectional shapes and sizes at two points along the axis.

39. The tool of claim 1 wherein the agitator includes a first agitator element and a second agitator element, with at least a portion of the second agitator element being spaced apart from the first agitator element, the first agitator element having a first shape and size and the second agitator element having a second shape and size, with the first shape being different than the second shape, or the first size being different than the second size, or both.

40. The tool of claim 39 wherein the process location has an inner region positioned to be generally proximate to an inner region of the microfeature workpiece, and an outer region positioned to be generally proximate to an outer region of the microfeature workpiece, and wherein the second agitator element is positioned inwardly from the first agitator element, the first agitator element being smaller than the second agitator element.

41. The tool of claim 39 wherein the first shape is geometrically similar to the second shape and wherein the first size is different than the second size.

42. The tool of claim 39 wherein the workpiece support includes a generally circular seal positioned to extend around a peripheral region of the microfeature workpiece, and wherein the first agitator element is elongated along an elongation axis and is positioned pass over the seal with the elongation axis generally tangent to a portion of the seal, and wherein the second agitator element is positioned inwardly from the first agitator element, still further wherein the first agitator element is smaller than the second agitator element.

43. The tool of claim 1 wherein the agitator includes a plurality of agitator elements and wherein at least a first one of the agitator elements is elongated along a first axis and at least a second one of the agitator elements is elongated along a second axis non-parallel to the first axis.

44. The tool of claim 1 wherein the agitator includes a first agitator element elongated along a first axis and a second agitator element elongated along a second axis generally orthogonal to the first axis, and wherein at least one of the agitator and the workpiece support is movable relative to the other along a generally linear motion path inclined at a first acute angle relative to the first axis, the generally linear motion path being inclined at a second acute angle relative to the second axis.

45. The tool of claim 1 wherein the process location includes a portion of a generally planar process plane, and wherein the reactor further comprises an electrode support positioned to carry a thieving electrode remote from the process plane.

46. The tool of claim 1 wherein the reactor includes an electrode support configured to carry at least one electrode in fluid communication with the process location.

47. The tool of claim 46 wherein the electrode support has a plurality of electrode chambers at least partially separated from each other by dielectric barriers, with gaps between the dielectric barriers forming a corresponding plurality of virtual electrode locations spaced apart from the process location.

48. The tool of claim 47, further comprising a plurality of electrodes disposed in the corresponding plurality of electrode chambers.

49. The tool of claim 47, further comprising an electrode thief spaced apart from the process plane, the electrode thief being positioned in fluid communication

with the process location to receive ions from the processing fluid that would otherwise attach to the microfeature workpiece.

50. The tool of claim 47 wherein the electrode support is positioned to carry a thieving electrode remote from the process plane.

51. The tool of claim 50, further comprising the thieving electrode.

52. The tool of claim 50, further comprising:

the thieving electrode;

a contact electrode carried by the workpiece support and positioned to make electrical contact with a microfeature workpiece when the workpiece support carries the microfeature workpiece;

at least one anode spaced apart from the process location; and

one or more power supplies coupled among the contact electrode, the thieving electrode and the at least one anode to provide current to the at least one anode at a potential greater than potentials provided to the thieving electrode and the contact electrode.

53. The tool of claim 46 wherein the agitator includes a plurality of agitator elements, with the agitator elements being movable back and forth relative to the process location along a generally linear motion path, and wherein the reactor further comprises an at least partially enclosed agitator chamber positioned between the electrode support and the process location, the agitator chamber housing the plurality of agitator elements.

54. The tool of claim 1 wherein the workpiece support is positioned to rotate a microfeature workpiece at the process location about an axis generally normal to a plane of the process location while the agitator moves relative to the process location.

55. The tool of claim 1 wherein the workpiece support is movable while the agitator moves relative to the process location.

56. The tool of claim 1 wherein the workpiece support is stationary while the agitator moves relative to the process location.

57. The tool of claim 1 wherein the reactor includes:

an electrode support configured to carry at least one electrode, the electrode support being in fluid communication with the process location; and

an electric field control element positioned along a flow path between the electrode support and the process location, the electric field control element being configured to control an electrical current density in the processing fluid at the process location to have a first value at a first circumferential site of the process location and a second value different than the first value at a second circumferential site of the process location.

58. The tool of claim 57 wherein the electric field control element includes a slot having a first region with a first width and a second region with a second width greater than the first width.

59. The tool of claim 57 wherein the electric field control element includes a plurality of apertures, with apertures in a first region of the electric field control element providing a first open area and apertures in a second region of the electric field control element providing a second open area greater than the first open area.

60. The tool of claim 57 wherein the vessel includes vanes aligned along axes extending between the electric field control element and the process location.

61. The tool of claim 57 wherein the vessel includes a first portion and a second portion sealably coupled to the first portion, and wherein the electric field

control element includes a gasket sealably positioned between the first and second portions.

62. The tool of claim 1 wherein the processing fluid includes a first processing fluid, and wherein the reactor further comprises a nozzle coupleable to a source of a second processing fluid and positioned above the process location to direct a stream of the second processing fluid toward a microfeature workpiece carried by the workpiece support.

63. The tool of claim 62 wherein the workpiece support is movable between a first position to carry a microfeature workpiece in contact with the first processing fluid at the process location, and a second position above the first position to place the microfeature workpiece in a path of the stream of second processing fluid directed by the nozzle.

64. A wet chemical processing reactor, comprising:

a process vessel configured to receive a processing fluid, the process vessel having a process location;

a workpiece support configured to at least partially immerse a workpiece in a processing fluid at the process location of the vessel;

a processing fluid agitator located within the vessel at least proximate to the process location, the agitator having a plurality of agitator surfaces, at least one of the agitator and the workpiece support being movable relative to the process location so as to agitate processing fluid at least proximate to the process location;

an actuator operatively coupled to the at least one of the agitator and the workpiece support; and

an electrode support positioned in the process vessel and configured to carry at least one electrode in fluid communication with the process location.

65. The reactor of claim 64 wherein the electrode support is positioned to carry a thieving electrode remote from the process plane.

66. The reactor of claim 65, further comprising the thieving electrode.

67. The reactor of claim 65, further comprising:

the thieving electrode;

a contact electrode carried by the workpiece support and positioned to make electrical contact with a microfeature workpiece when the workpiece support carries the microfeature workpiece;

at least one anode spaced apart from the process location; and

one or more power supplies coupled among the contact electrode, the thieving electrode and the at least one anode to provide current to the at least one anode at a potential greater than potentials provided to the thieving electrode and the contact electrode.

68. The reactor of claim 64 wherein the agitator includes a plurality of agitator elements, with the agitator elements being movable back and forth relative to the process location along a generally linear motion path, and wherein the system further comprises an at least partially enclosed agitator chamber positioned between the electrode support and the process location, the agitator chamber housing the plurality of agitator elements.

69. The reactor of claim 64 wherein the processing fluid includes a first processing fluid, and wherein the system further comprises a nozzle coupleable to a source of a second processing fluid and positioned above the process location to direct a stream of the second processing fluid toward a microfeature workpiece carried by the workpiece support.

70. The reactor of claim 64 wherein the workpiece support is movable between a first position to carry a microfeature workpiece in contact with the first processing fluid at the process location, and a second position above the first position to place the microfeature workpiece in a path of the stream of second processing fluid directed by the nozzle.

71. The reactor of claim 64 wherein the electrode support has a plurality of electrode chambers at least partially separated from each other by barriers, gaps between the barriers forming a corresponding plurality of virtual electrode locations spaced apart from the process plane.

72. The reactor of claim 71, further comprising a plurality of electrodes disposed in the corresponding plurality of electrode chambers.

73. The reactor of claim 71, further comprising an electrode thief spaced apart from the process plane, the electrode thief being positioned in fluid communication with the process location to receive ions from the processing fluid that would otherwise attach to the microfeature workpiece.

74. The reactor of claim 64, further comprising a magnet positioned at least proximate to the process location, the magnet being positioned to impose a magnetic field at the process location to orient material deposited on a microfeature workpiece, and wherein the electrode support is movable relative to the vessel between a process position and a removed position along a motion path that does not pass through the process plane.

75. The reactor of claim 74 wherein the magnet includes a permanent magnet.

76. The reactor of claim 64, further comprising an electric field control element positioned along a flow path between the electrode support and the process location, the electric field control element being configured to control an electrical current density in the processing fluid at the process location to have a first value at a first circumferential site of the process location and a second value different than the first value at a second circumferential site of the process location, the first and second circumferential sites being approximately the same distance from the center of the process location.

77. The reactor of claim 76 wherein the electric field control element includes a slot having a first region with a first width and a second region with a second width greater than the first width.

78. The reactor of claim 76 wherein the electric field control element includes a plurality of apertures, with apertures in a first region of the electric field control element providing a first open area and apertures in a second region of the electric field control element providing a second open area greater than the first open area.

79. The reactor of claim 76 wherein the vessel includes vanes aligned along axes extending between the electric field control element and the process location.

80. The reactor of claim 76 wherein the vessel includes a first portion and a second portion sealably coupled to the first portion, and wherein the electric field control element includes a gasket sealably positioned between the first and second portions.

81. The reactor of claim 64 wherein the workpiece support is rotatable to rotate the microfeature workpiece relative to the vessel

82. The reactor of claim 64 wherein the workpiece support is positioned to rotate a microfeature workpiece at the process location about an axis generally normal to a plane of the process location while the agitator moves relative to the process location.

83. The reactor of claim 64 wherein the workpiece support is movable while the agitator moves relative to the process location.

84. The reactor of claim 64 wherein the workpiece support is stationary while the agitator moves relative to the process location.

85. A system for processing microfeature workpieces, comprising:

a vessel configured to carry a processing fluid, the vessel having a process location positioned to receive a microfeature workpiece;

a workpiece support positioned at least proximate to the vessel, the workpiece support being positioned to carry a microfeature workpiece at the process location of the vessel during processing; and

an agitator having multiple spaced apart agitator surfaces positioned at least proximate to the process location, wherein at least one of the workpiece support and the agitator is movable back and forth along a generally linear path relative to the other while the workpiece support carries a microfeature workpiece.

86. The system of claim 85 wherein the vessel includes an agitator chamber volume that extends for a first distance generally normal to a plane of the process location, and wherein the agitator is disposed in the agitator chamber volume, and wherein the agitator surfaces extend for a second distance generally normal to the process location, the second distance being at least 30% of the first distance.

87. The system of claim 86 wherein the agitator chamber includes a plurality of sidewall portions extending downwardly away from the process location, at least one of the sidewall portions including a fluid entrance at least proximate to the process location, at least one of the sidewall portions further including a fluid exit at least proximate to the process location, with the agitator positioned between the fluid entrance and the fluid exit.

88. The system of claim 86 wherein the second distance is at least 70% of the first distance.

89. The system of claim 86 wherein the second distance is at least 90% of the first distance.

90. The system of claim 86 wherein a gap between the process location and an upper extremity of at least one agitator surface is about five millimeters or less.

91. The system of claim 86 wherein the chamber volume is bounded by a base portion.

92. The system of claim 91 wherein the agitator is movable relative to the base portion.

93. The system of claim 91 wherein the agitator is movable relative to the base portion and wherein a first gap between the process location and an upper extremity of the agitator surfaces is about five millimeters or less, and wherein a second gap between the base and a lower extremity of the agitator surfaces is about five millimeters or less.

94. The system of claim 91 wherein at least part of the base portion is porous.

95. The system of claim 91 wherein the chamber volume is bounded by a plurality of sidewall portions extending downwardly away from the process location to the base portion, and wherein the base portion includes a first surface facing toward the process location and a second surface facing opposite from the first surface, and wherein the second surface is inclined to have a higher elevation toward a perimeter of the process location than toward a center of the process location.

96. The system of claim 85 wherein the workpiece support is positioned to rotate the microfeature workpiece about an axis generally normal to a face of the microfeature workpiece.

97. The system of claim 85 wherein the agitator includes a plurality of elongated agitator elements and wherein at least one agitator element has a first surface and a second surface facing opposite from the first surface, the first and second surfaces being canted outwardly and downwardly away from an axis positioned between the surfaces and normal to the process location.

98. The system of claim 97 wherein the at least one agitator element has a generally diamond shaped cross-section when intersected by a plane generally normal to the process location.

99. The system of claim 97 wherein the at least one agitator element has a generally triangular cross-sectional shape when intersected by a plane generally normal to the process location.

100. The system of claim 97 wherein at least one of the first and second surfaces is curved.

101. The system of claim 85 wherein the process location is positioned to receive a microfeature workpiece having a maximum width at the process location and wherein the system further comprises a controller operatively coupled to at least one of the agitator and the workpiece support, the controller being configured to move at least one of the agitator and the workpiece support relative to the other along the generally linear path by a distance that is less than the maximum width.

102. The system of claim 85, further comprising a controller operatively coupled at least one of the agitator and the workpiece support, the controller being configured to move the at least one of the agitator and the workpiece support relative to the other in a reciprocal manner along the generally linear axis, with a stroke of the relative motion changing between at least two successive reciprocations.

103. The system of claim 85 wherein the agitator includes a plurality of elongated agitator elements and wherein the system further comprises a controller operatively coupled to the agitator to move each of the agitator elements with a spacing between adjacent agitator elements remaining constant as the agitator moves.

104. The system of claim 85 wherein the agitator includes a plurality of agitator elements and wherein at least a first one of the agitator elements is elongated along a first axis and at least a second one of the agitator elements is elongated along a second axis non-parallel to the first axis.

105. The system of claim 85 wherein the plurality of agitator elements includes a first agitator element elongated along a first axis and a second agitator element elongated along a second axis generally orthogonal to the first axis, and wherein at least one of the agitator and the workpiece support is movable relative to the other along a generally linear motion path inclined at a first acute angle relative to the first axis, the generally linear motion path being inclined at a second acute angle relative to the second axis.

106. The system of claim 85 wherein the agitator includes a first agitator element having a first shape and size and a second agitator element having a second shape and size, with the first shape being different than the second shape, or the first size being different than the second size, or both.

107. The system of claim 106 wherein the process location has an inner region positioned to be generally proximate to an inner region of the microfeature workpiece, and an outer region positioned to be generally proximate to an outer region of the microfeature workpiece, and wherein the second agitator element is positioned inwardly from the first agitator element, the first agitator element being smaller than the second agitator element.

108. The system of claim 106 wherein the first shape is geometrically similar to the second shape and wherein the first size is different than the second size.

109. The system of claim 106 wherein the workpiece support includes a generally circular seal positioned to extend around a peripheral region of the microfeature workpiece, and wherein the first agitator element is elongated along an elongation axis and is positioned pass over the seal with the elongation axis generally tangent to a portion of the seal, and wherein the second agitator element is positioned inwardly from the first agitator element, still further wherein the first agitator element is smaller than the second agitator element.

110. The system of claim 85 wherein the agitator is at least partially transmissive to the processing fluid to allow the processing fluid to pass through the agitator.

111. The system of claim 110 wherein the agitator includes a generally porous material.

112. The system of claim 110 wherein the agitator includes a plurality of highly flow-restrictive apertures extending from the first surface to the second surface.

113. The system of claim 85 wherein the agitator includes an electrically conductive material.

114. The system of claim 85 wherein the agitator includes an electrically insulative material.

115. The system of claim 85 wherein the agitator includes at least one agitator element elongated along an axis, and wherein the agitator element has

different cross-sectional shapes, different cross-sectional sizes, both different cross-sectional shapes and sizes at two points along the axis.

116. A method of operating an integrated tool for wet chemical processing of microfeature workpieces having submicron features, comprising:

processing a microfeature workpiece in a wet chemical processing chamber by contacting a processing fluid with the microfeature workpiece at a process location and agitating the processing fluid by moving at least one of the workpiece and an agitator positioned proximate to the workpiece relative to the other, the agitator having at least one agitator surface, the wet chemical processing chamber being located at a first position in the tool;

removing the wet chemical processing chamber from the tool;

replacing the wet chemical processing chamber with a replacement wet chemical processing chamber by mounting the replacement wet chemical processing chamber to the tool at the first position; and

loading another microfeature workpiece in the replacement wet chemical processing using an automated workpiece transport system without calibrating the automated workpiece transport mechanism after replacing the wet chemical processing station.

117. The method of claim 116 wherein removing the wet chemical processing chamber from the tool includes disengaging the wet chemical processing chamber from positioning elements and attachment elements of the tool, and wherein replacing the wet chemical processing chamber with a replacement wet chemical processing chamber includes engaging the replacement wet chemical processing chamber with the positioning elements and attachment elements.

118. The method of claim 116 wherein the process location includes a portion of a generally planar process plane, and wherein processing the microfeature workpiece includes placing the microfeature workpiece in fluid communication with at least one electrode to electrolytically deposit a magnetically

sensitive material on the microfeature workpiece while the microfeature workpiece is subjected to a magnetic field at the process plane and while the microfeature workpiece is in fluid communication with the at least one electrode, and wherein the method further comprises removing the at least one electrode from fluid communication with the process plane without passing the at least one electrode through the process plane.

119. The method of claim 116 wherein processing the microfeature workpiece includes electrolytically depositing a material on the microfeature workpiece by directing at least a portion of the processing fluid toward the microfeature workpiece and adjacent to a plurality of electrodes positioned in a plurality of electrode chambers at least partially separated from each other by dielectric barriers, with gaps between the dielectric barriers forming a corresponding plurality of virtual electrode locations spaced apart from the process location.

120. The method of claim 116 wherein the microfeature workpiece has a maximum width and wherein the method further comprises reciprocating at least one of the microfeature workpiece and the agitator relative to the other along a generally linear motion path, with each of at least two temporally adjacent strokes of the motion covering a distance less than the maximum width.

121. The method of claim 116, further comprising:

reciprocating at least one of the microfeature workpiece and the agitator relative to the other along a generally linear axis; and

changing a reciprocal motion of the at least one of the microfeature workpiece and the agitator so that at least one stroke of the reciprocal motion covers an envelope different than an envelope covered by a subsequent stroke.

122. A method for processing a microfeature workpiece, comprising:

positioning a microfeature workpiece in contact with a processing fluid at a process plane of a process vessel;

processing the microfeature workpiece at the process plane by directing at least a portion of the processing fluid toward the microfeature workpiece to electrolytically deposit a magnetically sensitive material on the microfeature workpiece while the microfeature workpiece is subjected to a magnetic field at the process plane and while the microfeature workpiece is in fluid communication with at least one electrode spaced apart from the microfeature workpiece; and

removing the at least one electrode from fluid communication with the process plane without passing the at least one electrode through the process plane.

123. The method of claim 122 wherein removing the at least one electrode includes removing an electrode housing carrying a plurality of electrodes.

124. A method for manufacturing a processing apparatus for microfeature workpieces, comprising:

positioning a workpiece support at least proximate to a vessel, the workpiece support being configured to carry a microfeature workpiece at a process location of the vessel, the vessel being configured to receive a processing fluid;

selecting a characteristic of an agitator to have a selected effect on a diffusion layer of the processing fluid adjacent to the microfeature workpiece, the agitator including at least one agitator element, the characteristic including at least one of a number of agitator elements of the agitator, a spacing between the process location and the at least one agitator element, a stroke envelope of the at least one agitator element relative to the process location, and a stroke schedule of the at least one agitator element relative to the process location; and

mounting the agitator at least proximate to the process location, with at least one of the agitator and the workpiece support being movable relative to the other along a generally linear axis.

125. The method of claim 124, further comprising selecting the agitator to include six agitator elements, each having two oppositely facing, downwardly canted agitator surfaces.

126. The method of claim 124, further comprising selecting a stroke envelope of the at least one agitator element to be generally rectilinear and to have a length less than a maximum diameter of a microfeature workpiece carried by the workpiece support.

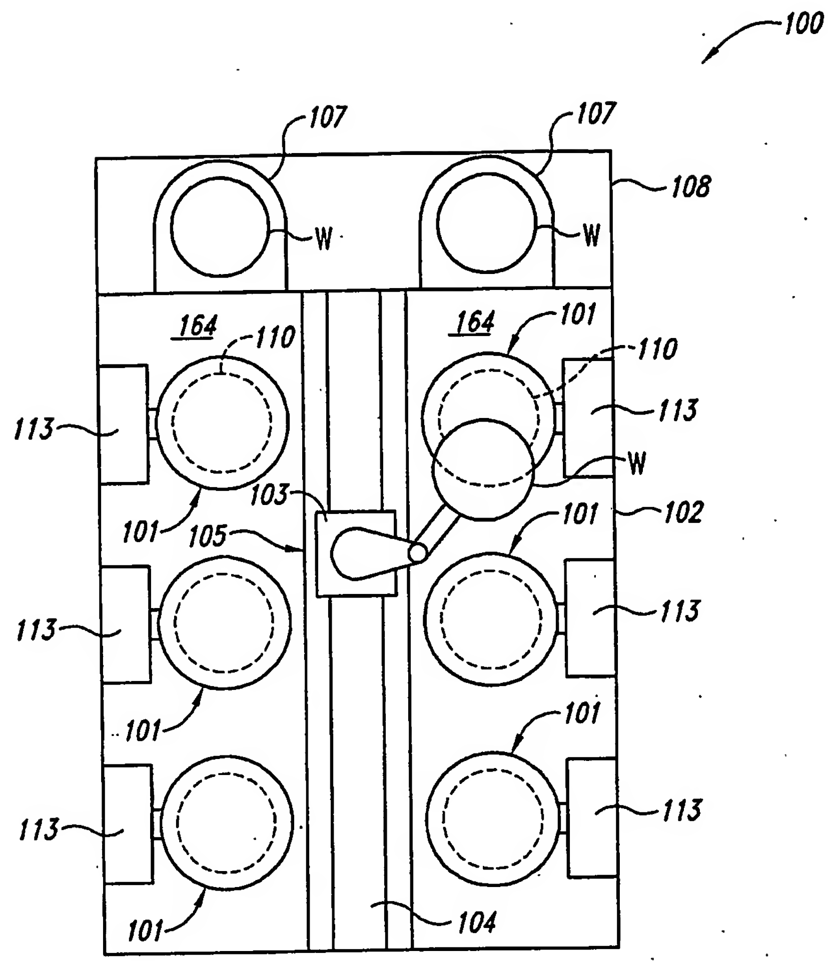
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Fig. 1

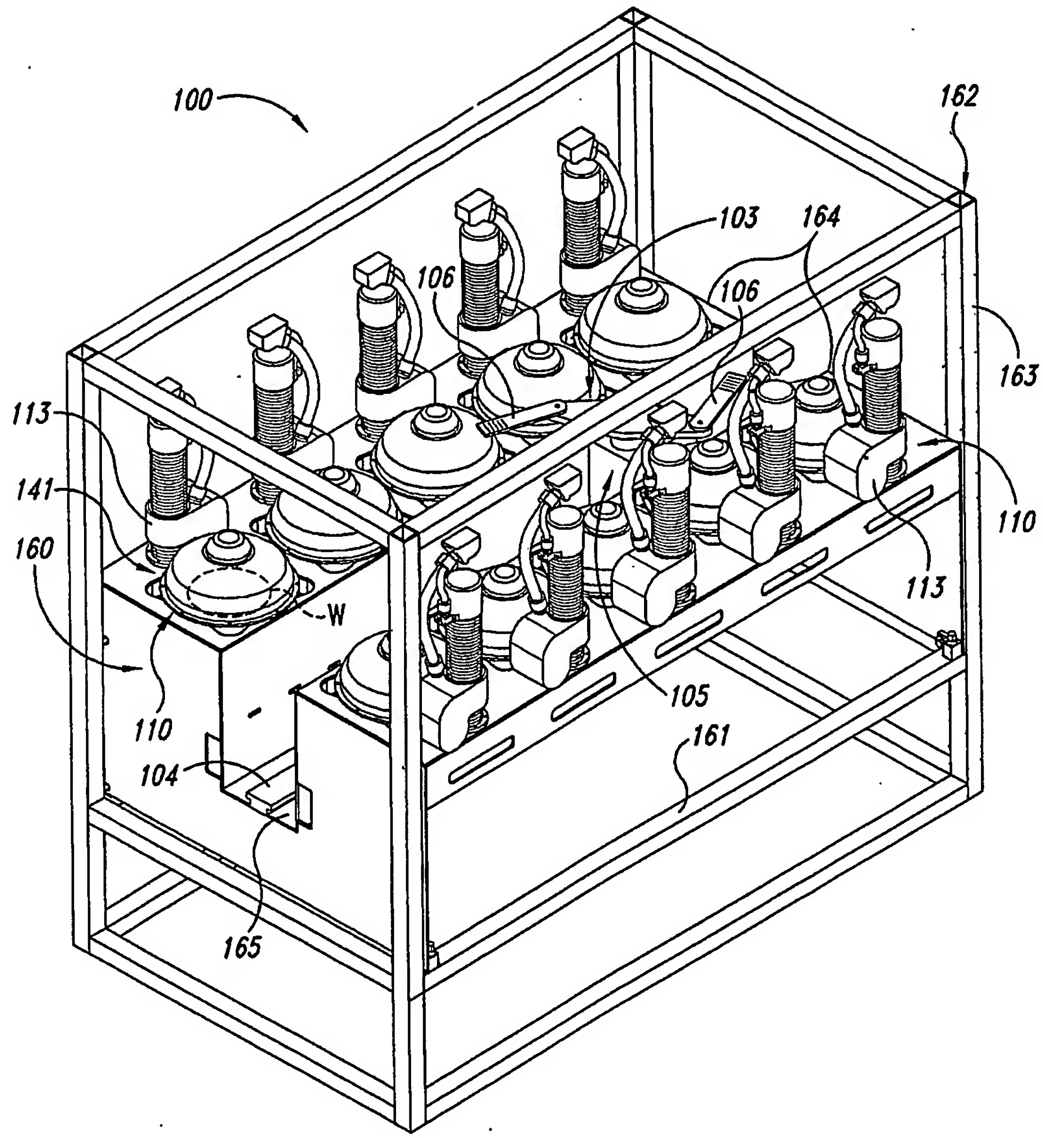
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Fig. 2A

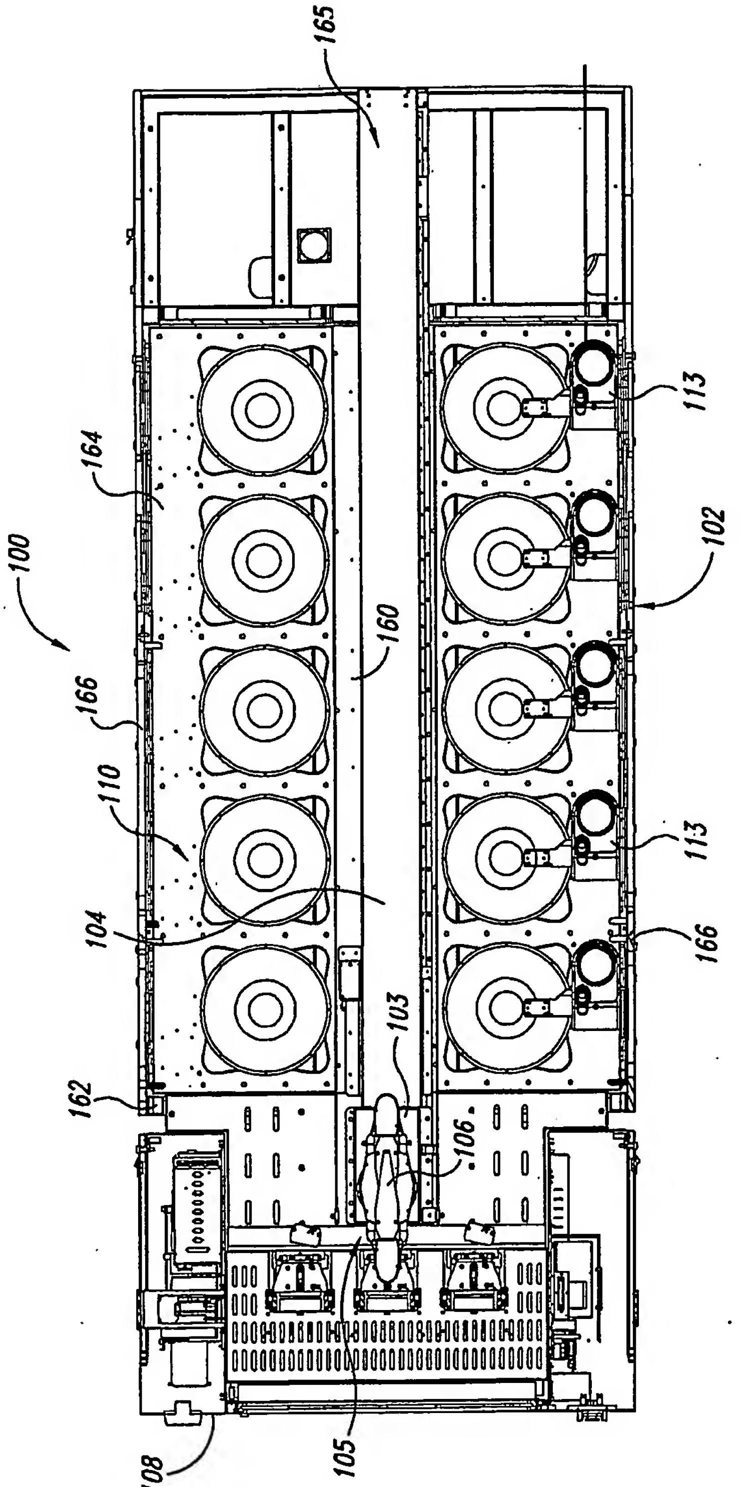

Fig. 2B

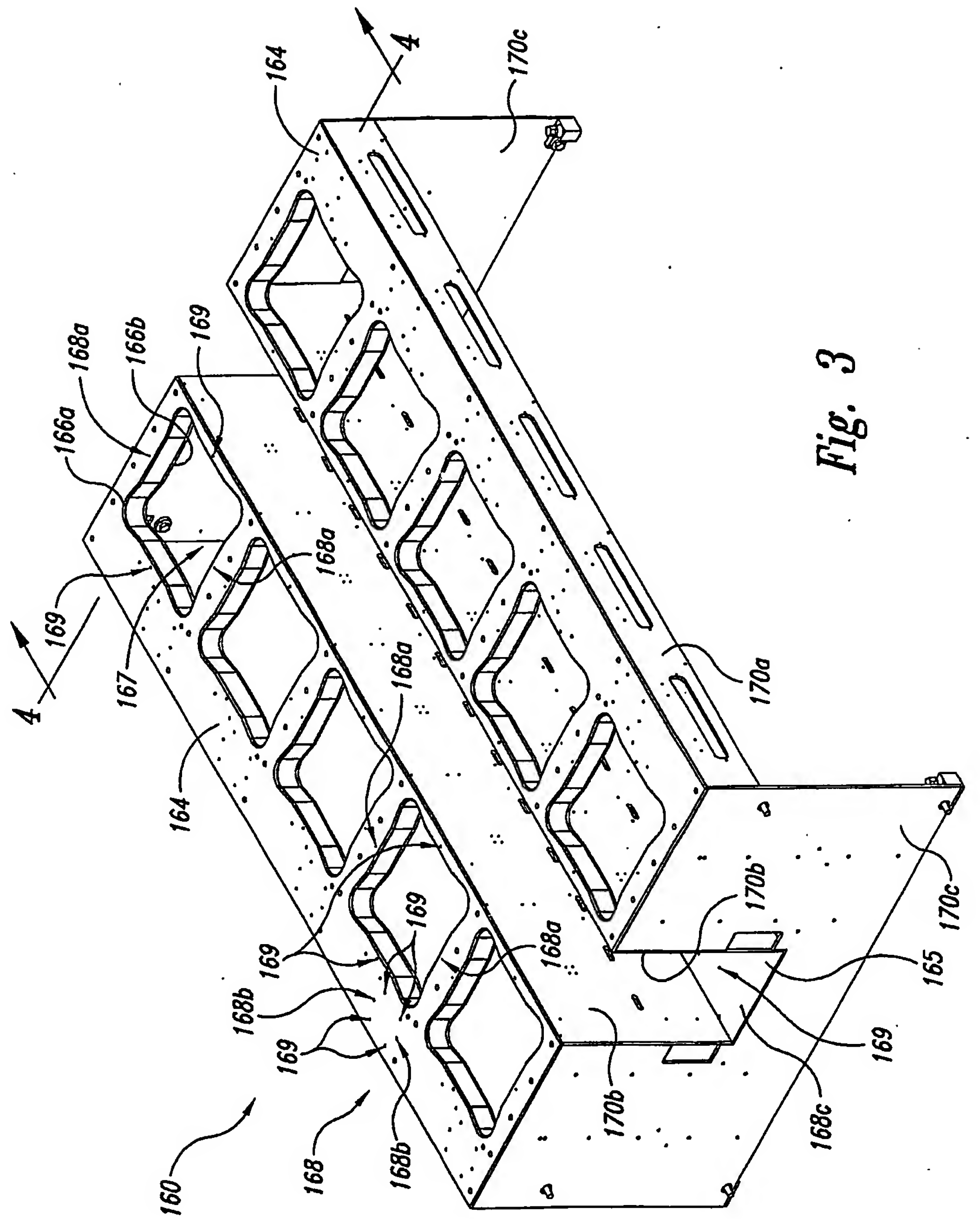
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Fig. 3

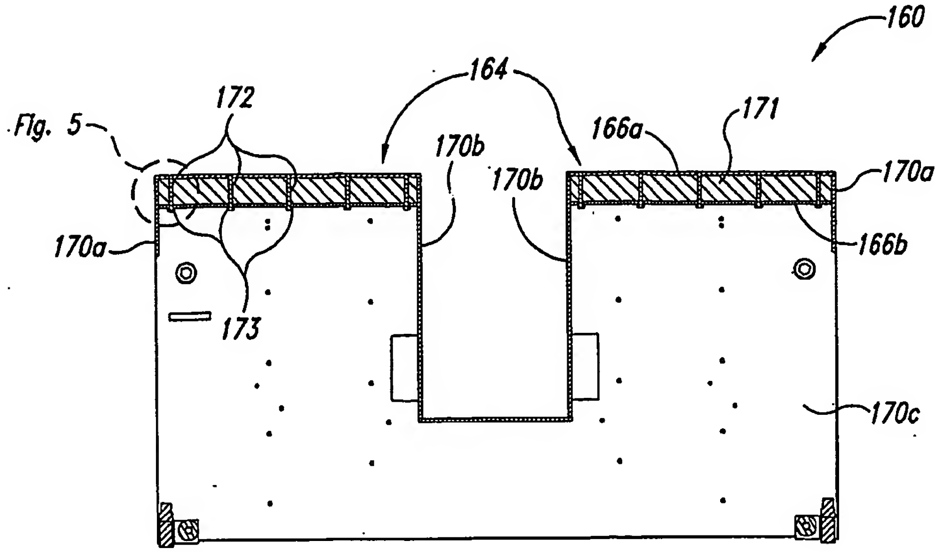
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Fig. 5
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Fig. 4

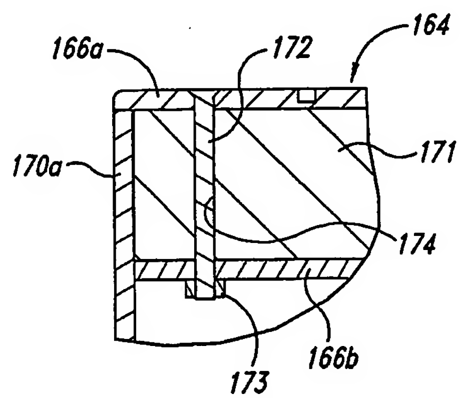
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Fig. 5

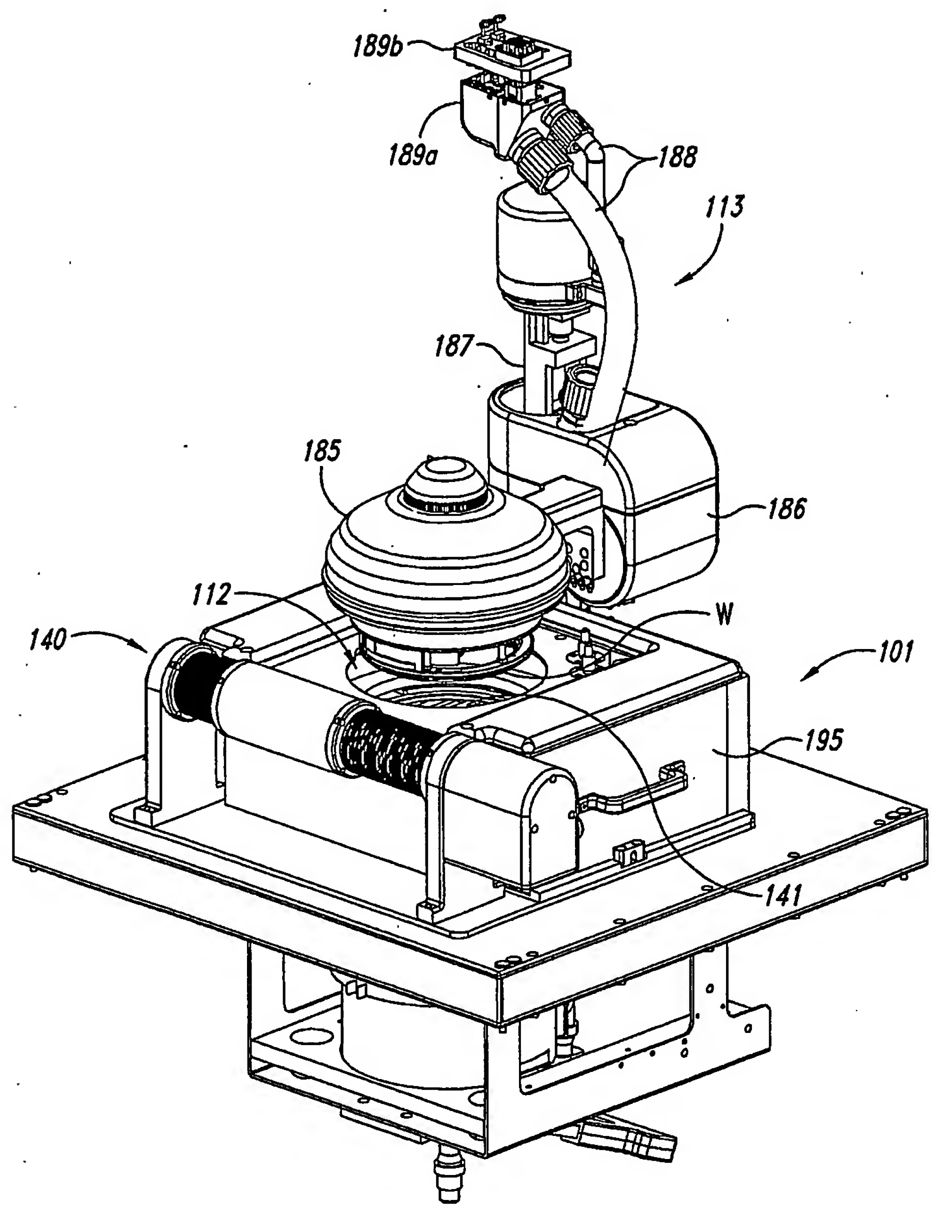

Fig. 6A

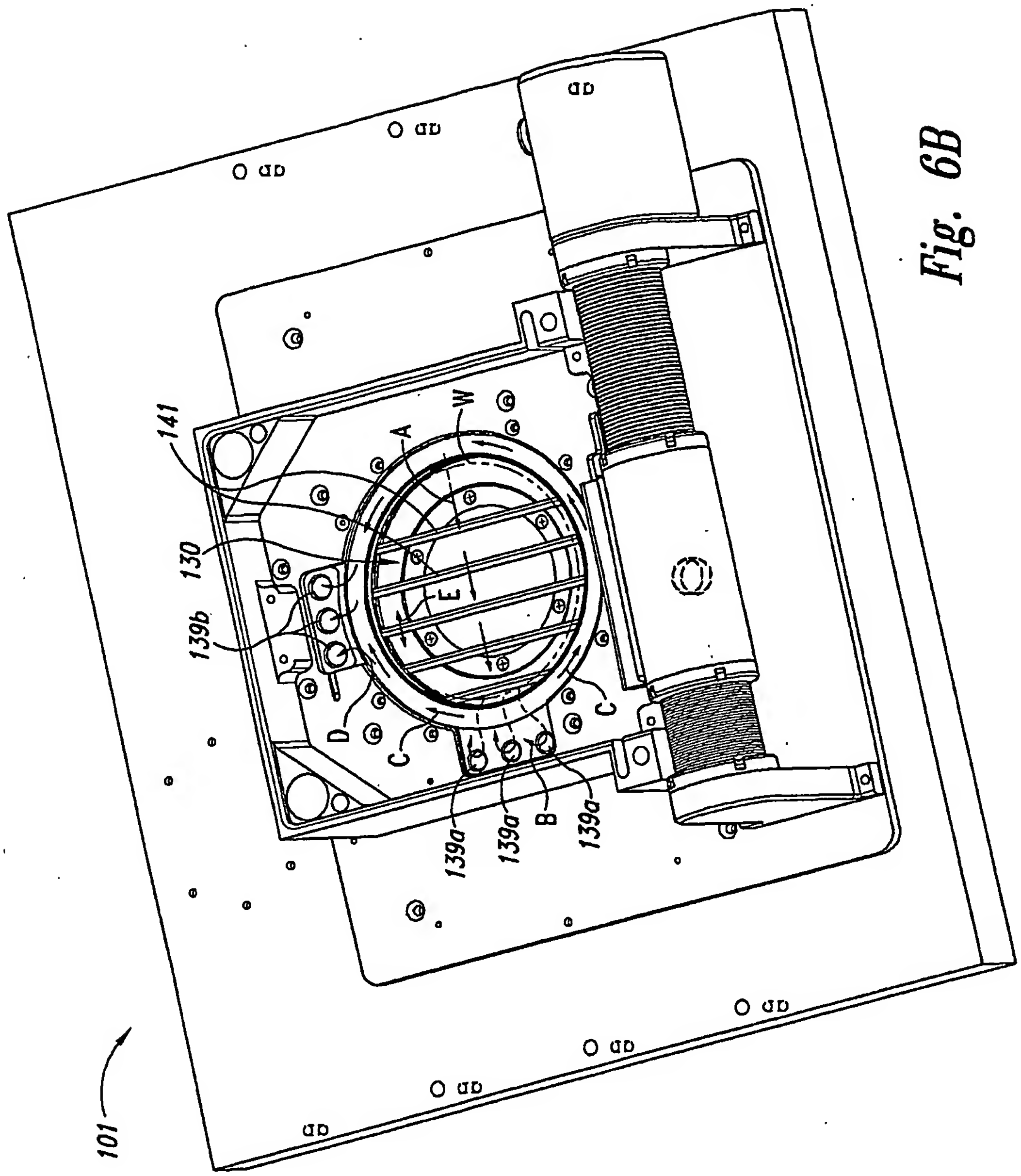

Fig. 6B

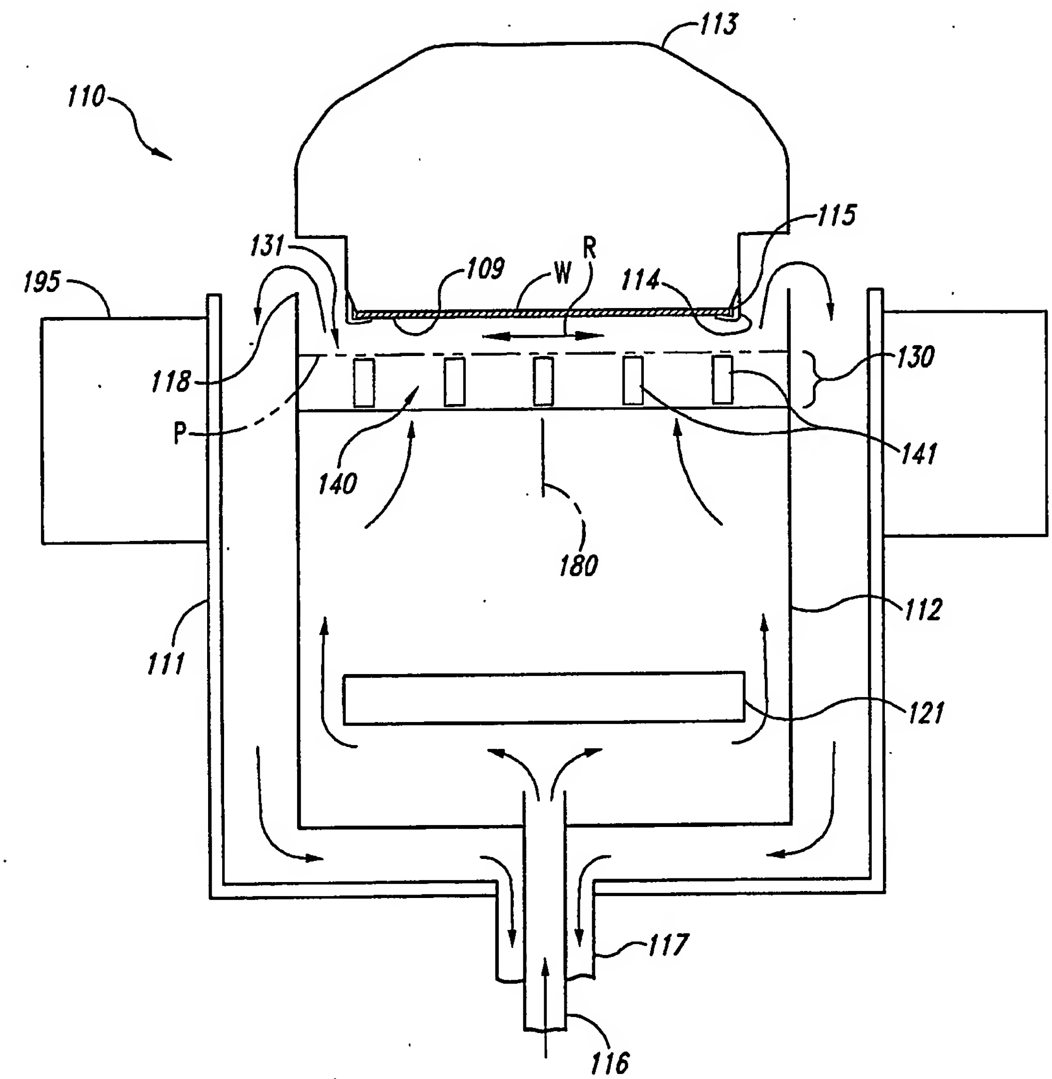
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Fig. 6C

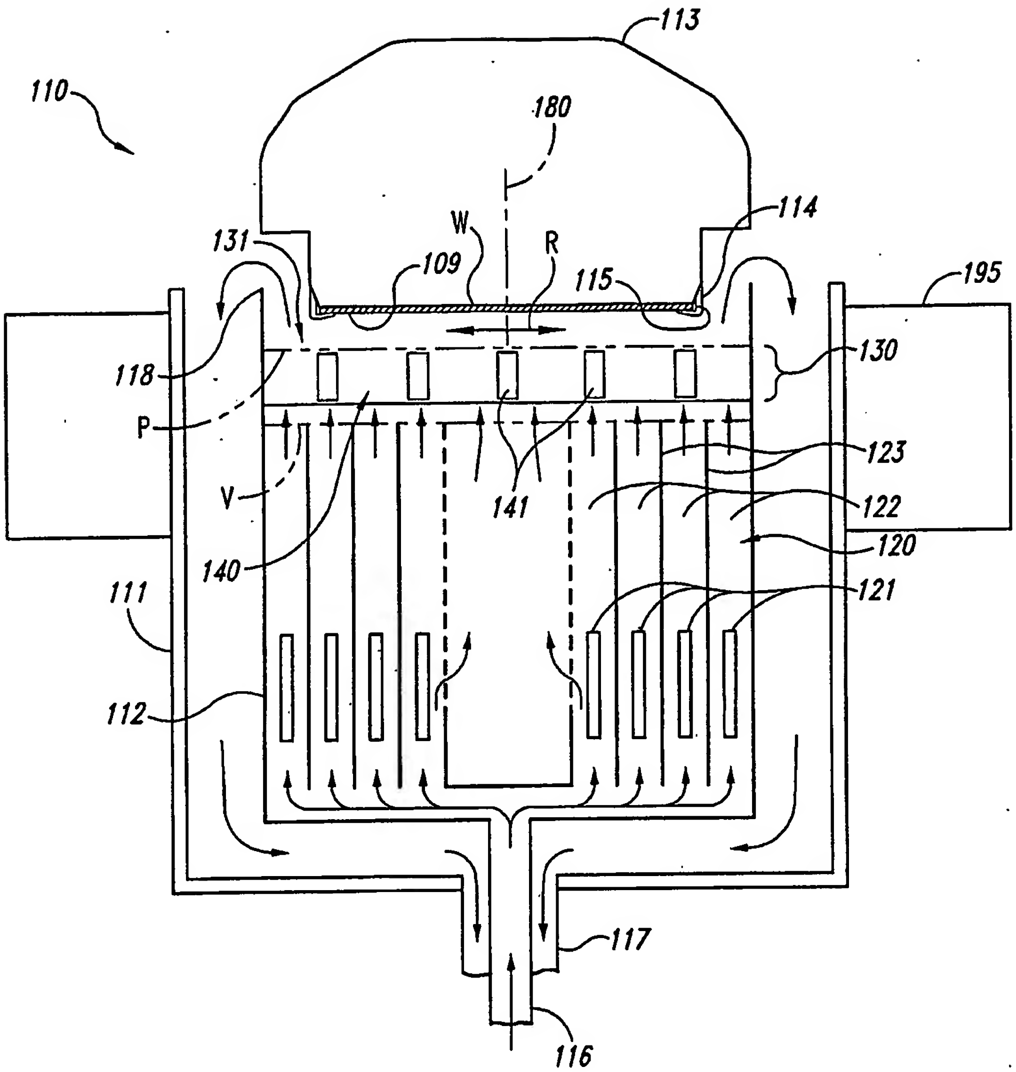
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Fig. 6D

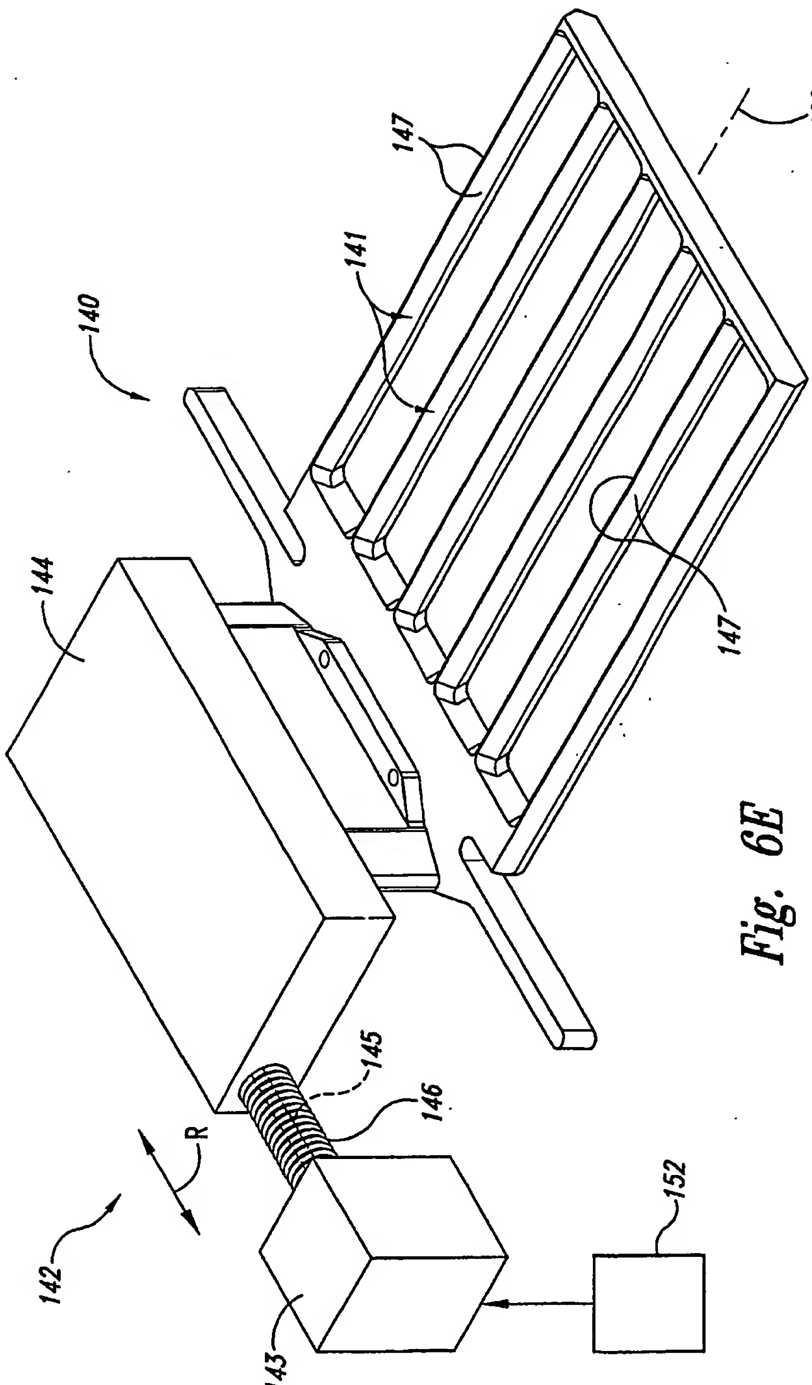
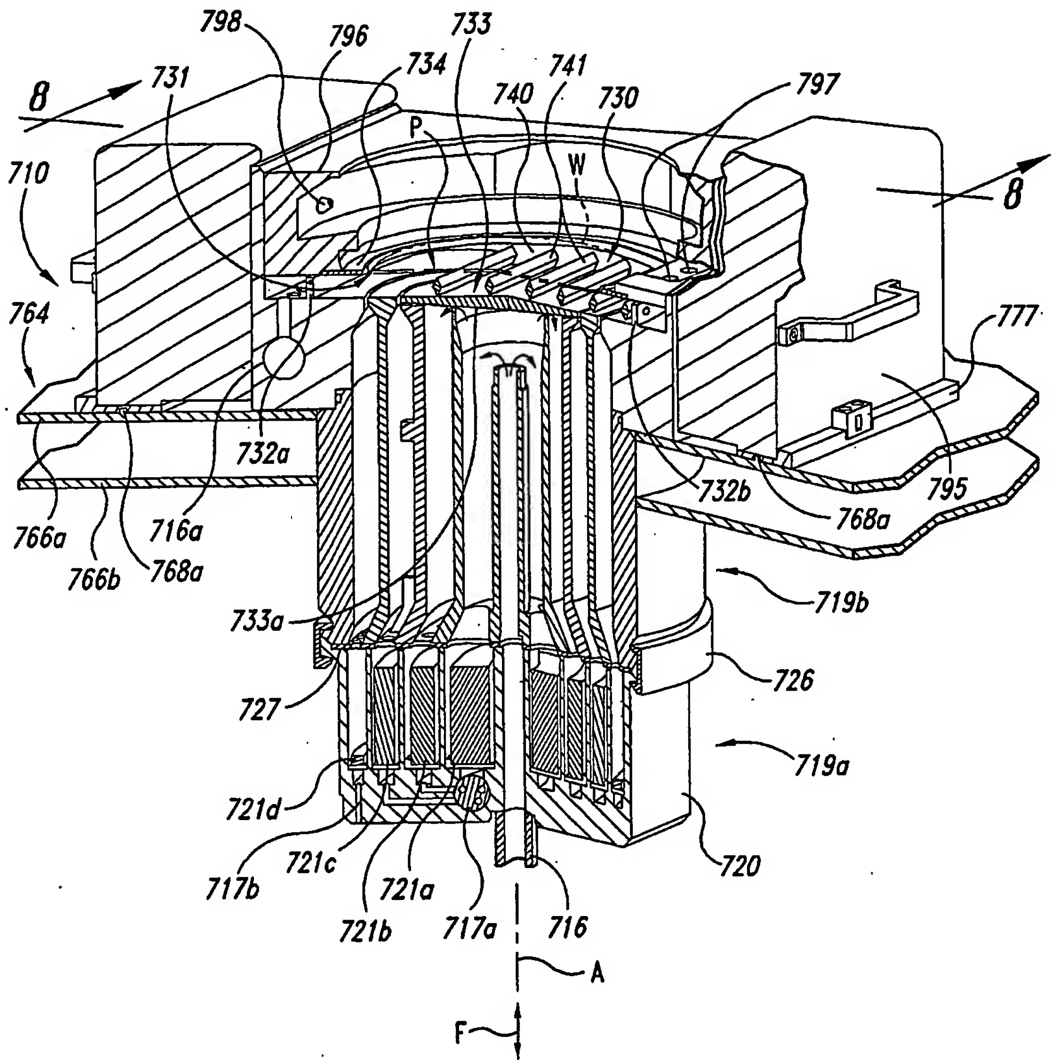


Fig. 6E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A
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Fig. 7

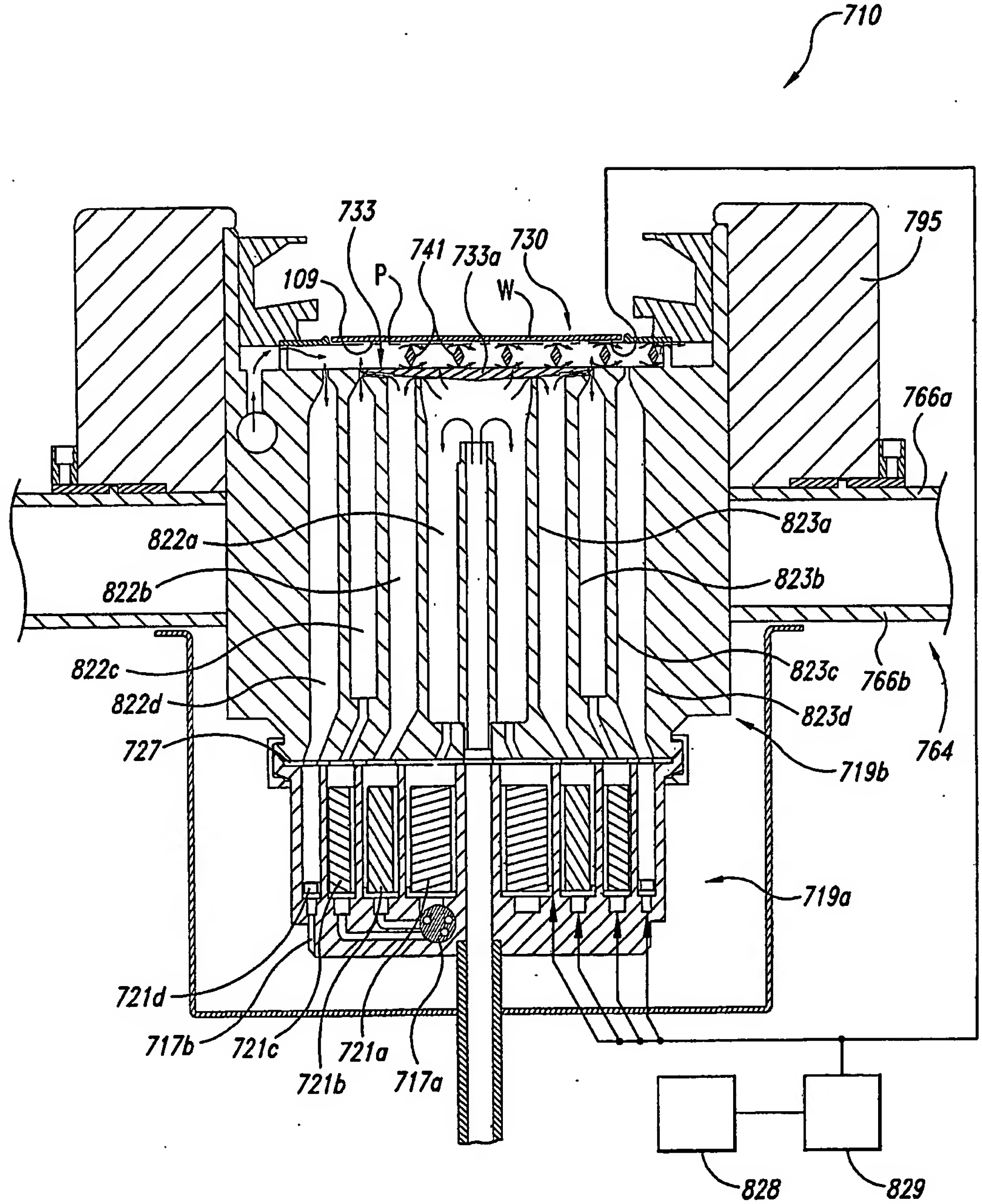
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Fig. 8

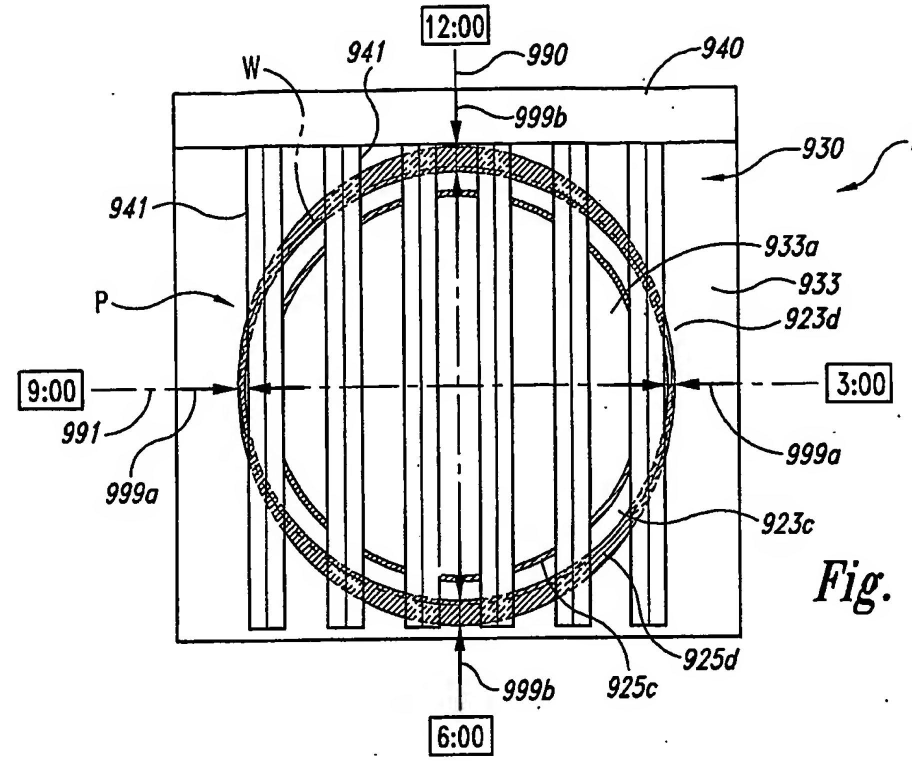
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Fig. 9

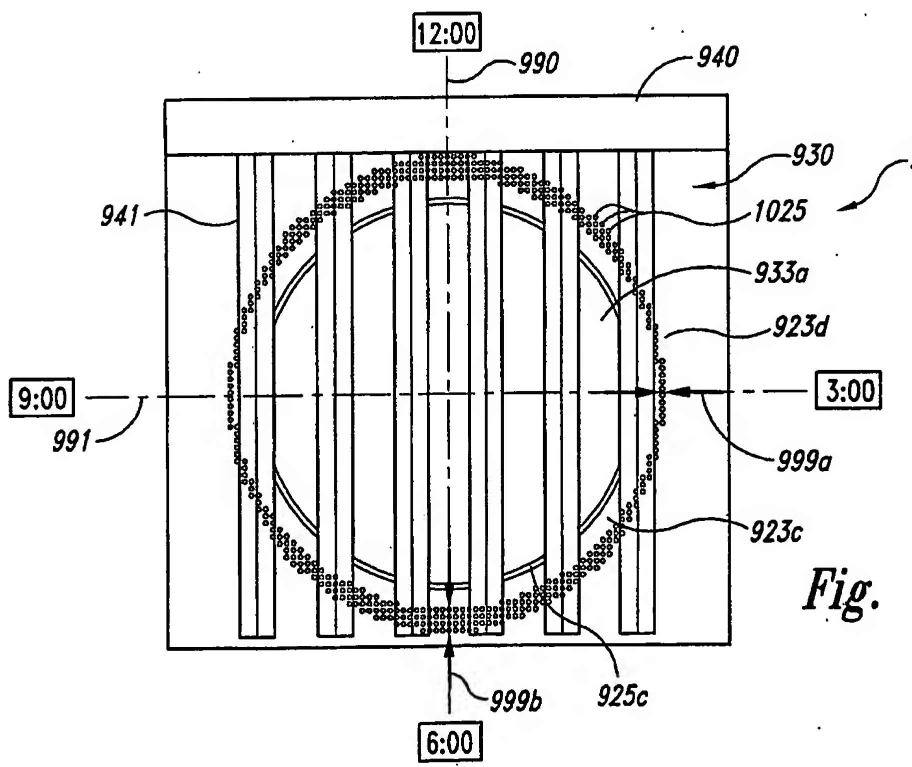
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Fig. 10

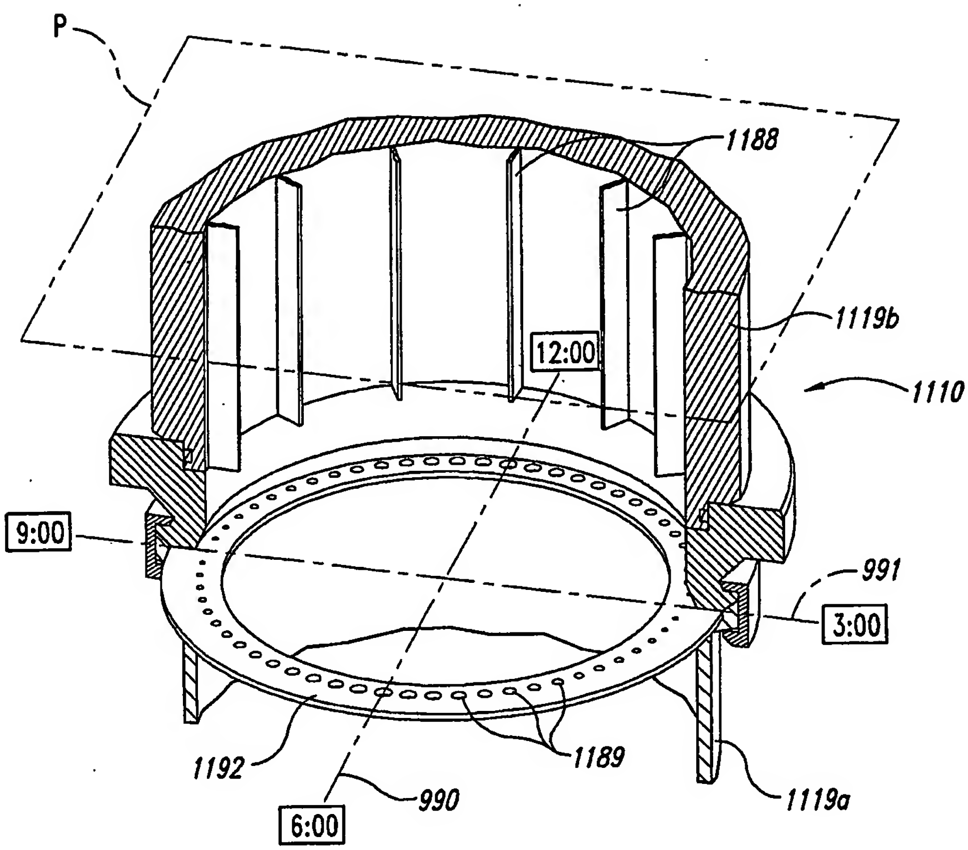

Fig. 11

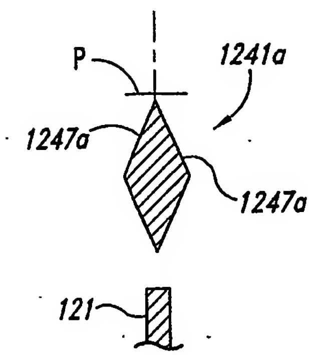

Fig. 12A

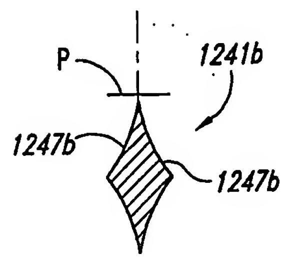

Fig. 12B

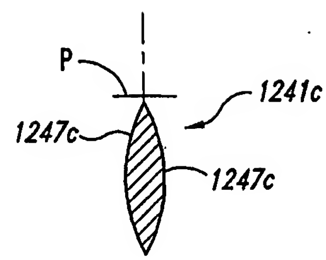

Fig. 12C

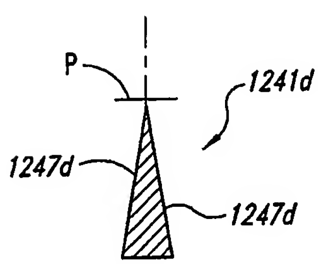

Fig. 12D

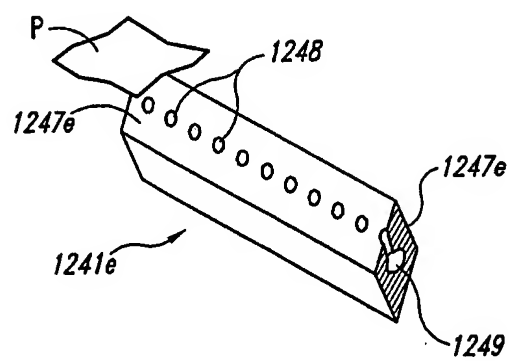

Fig. 12E

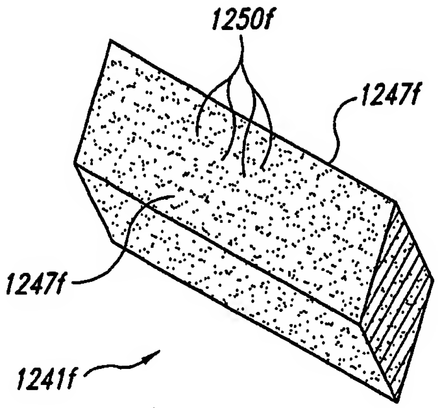

Fig. 12F

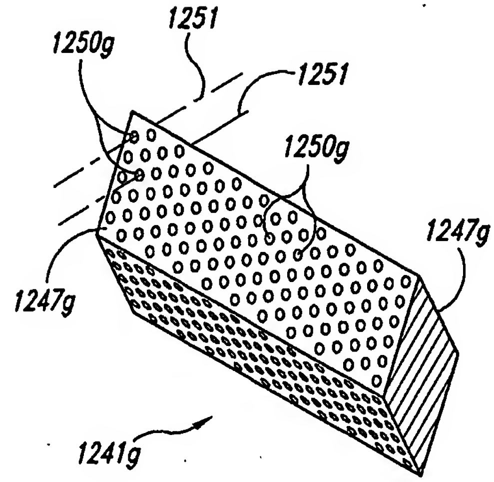

Fig. 12G

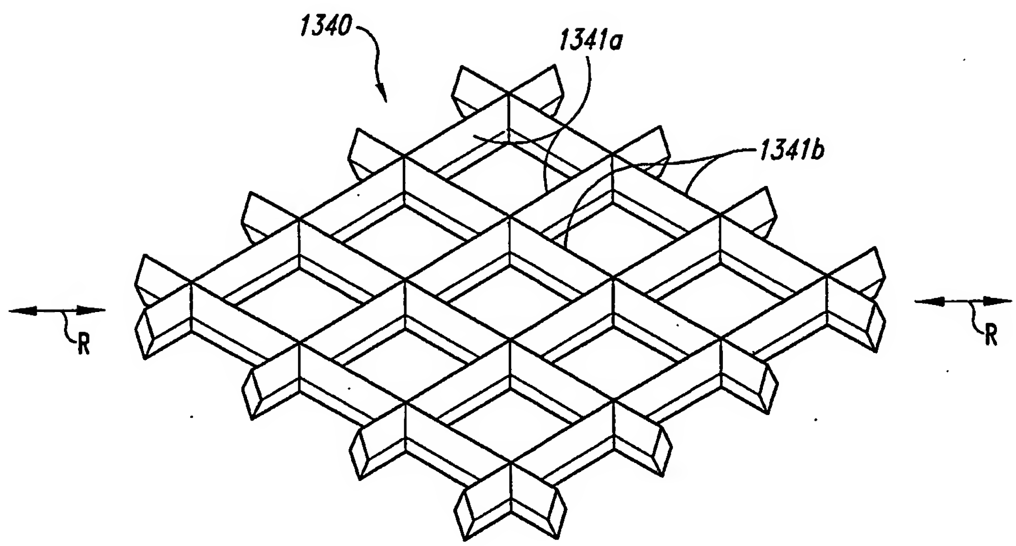

Fig. 13

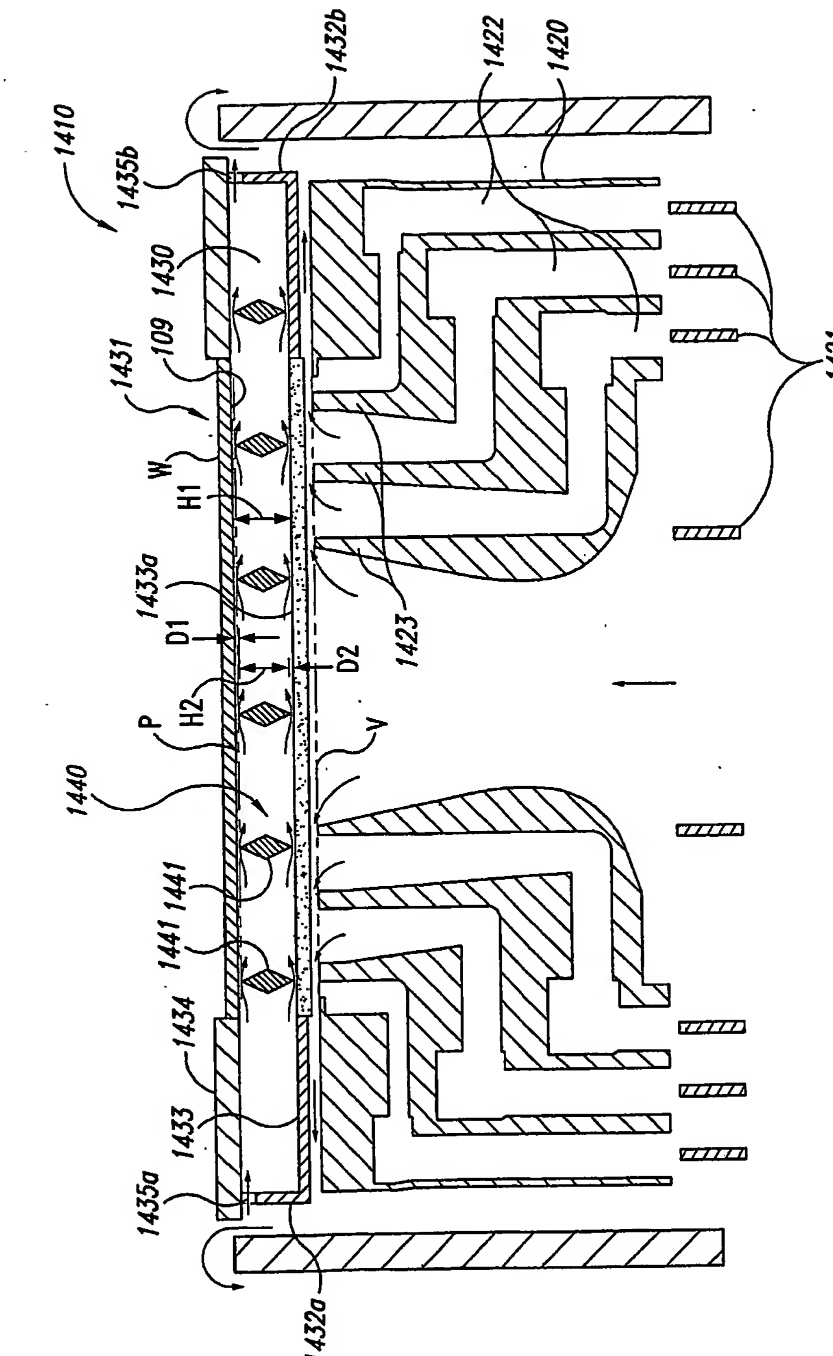
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Fig. 14

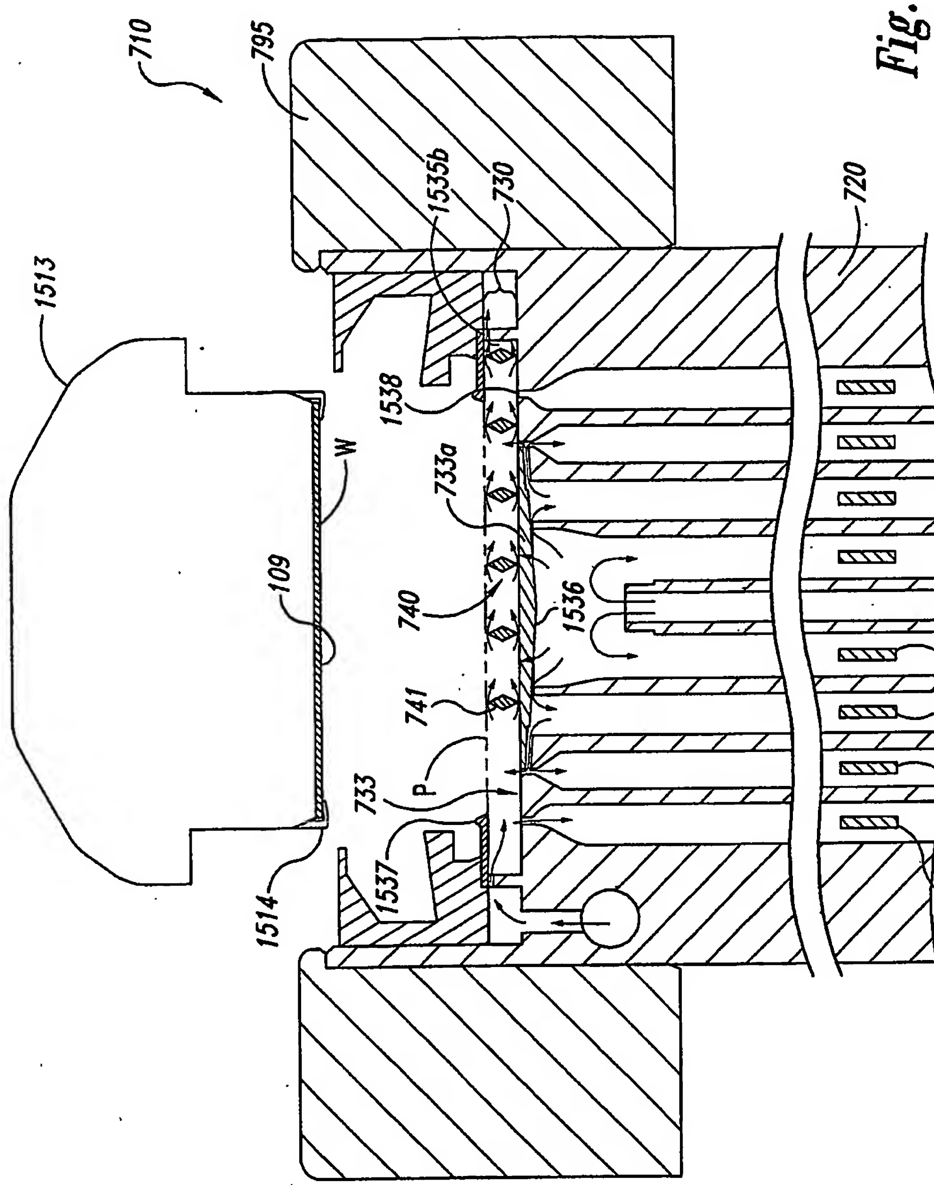
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Fig. 15

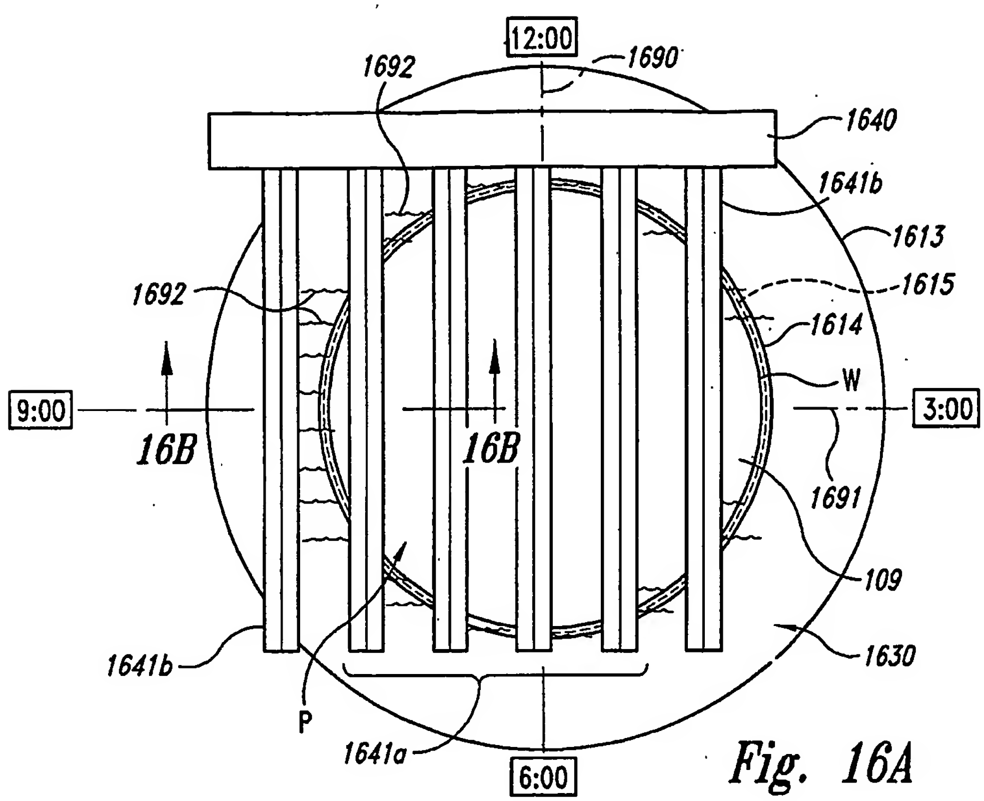

Fig. 16A

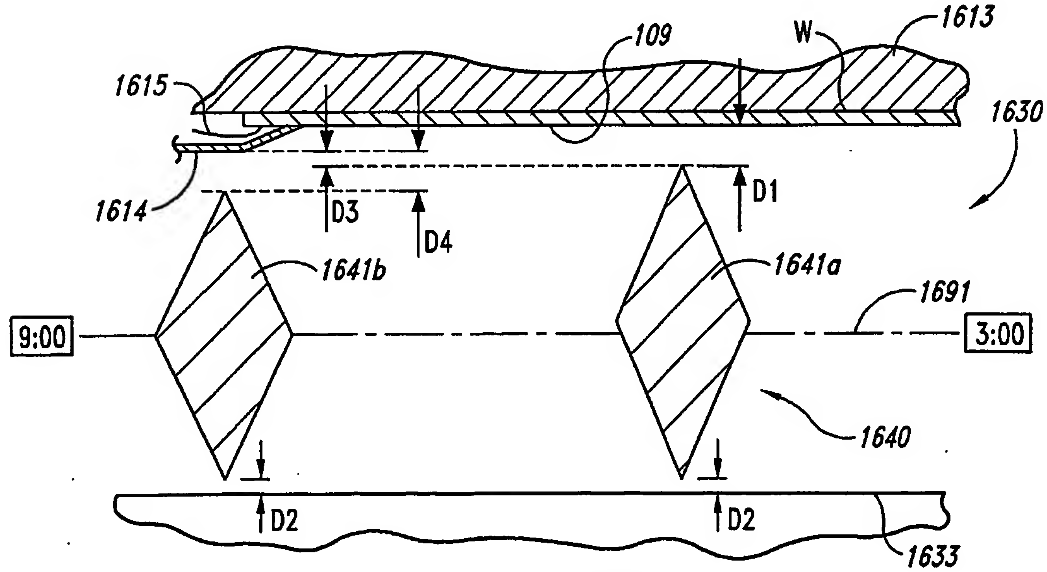

Fig. 16B

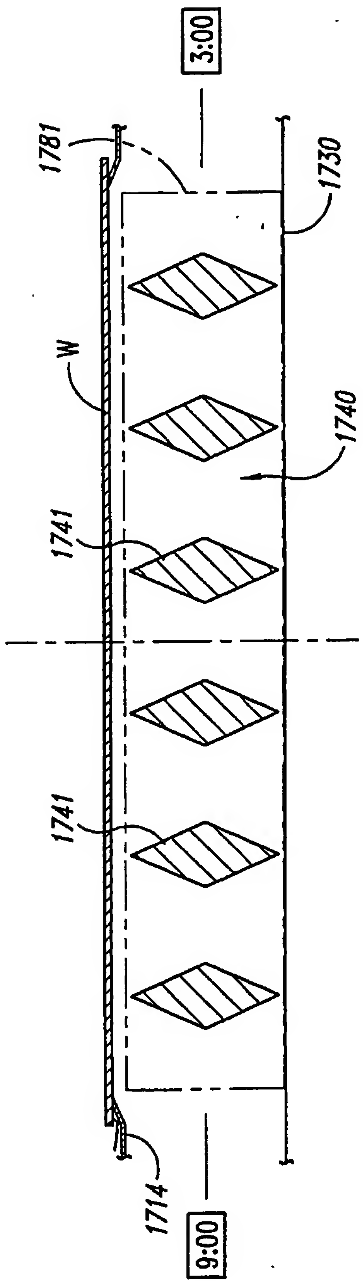

Fig. 17

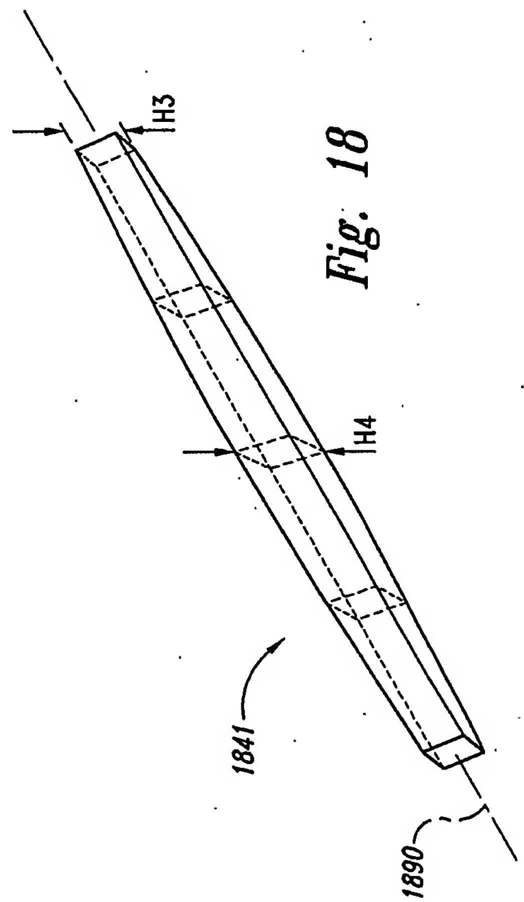

Fig. 18

Fig. 19A

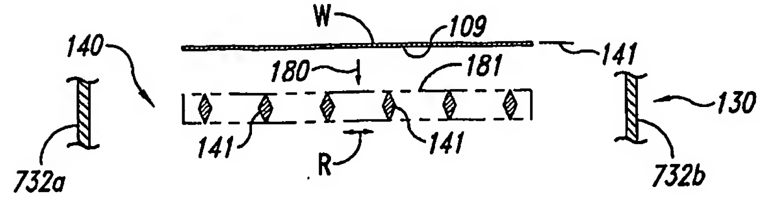

Fig. 19B

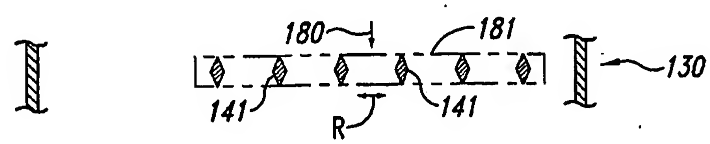

Fig. 19C

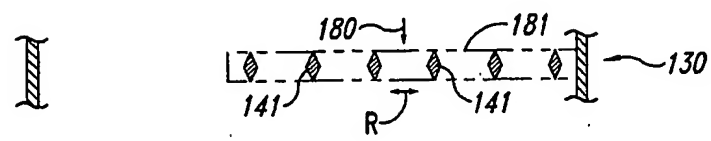

Fig. 19D

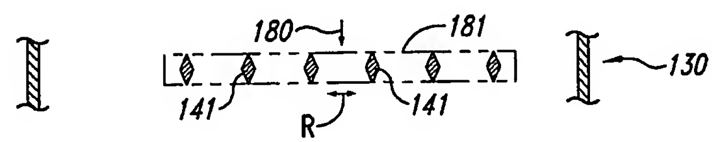

Fig. 19E

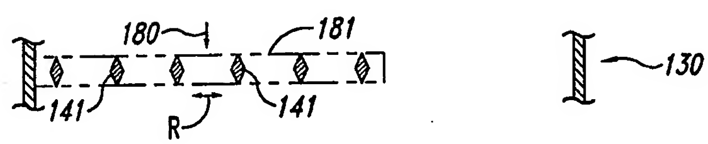

Fig. 19F